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BURIED AND RESURRECTED HILLS OF CENTRAL OZARKS[1]

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ABSTRACT

It is pointed out in this article that in the central Ozark region there are exceptional opportunities to study the relation of buried hills to the resultant structure in superjacent sediments. The first part of the article is a presentation of the actually observed facts, without discussion. In the second part, the writers present their interpretation.

Among the observed facts are the great relief of the pre-Cambrian surface; the thinness and character of the overlapping sediments; the observed dips, in some places as steep as 30°, in the adjacent limestones; the vertical magnitude of the resulting domes, with a maximum of more than 500 feet; the discovery of otherwise unsuspected porphyry knobs from the abnormal elevation of sedimentary contacts; and the remarkable lack of alignment of the dips, which follow a pattern of pre-Cambrian dendritic drainage.

In explanation of these facts, the writers point out that the dips are not the result of intrusion, as the igneous rocks are older than the sediments; that isostasy is not an adequate explanation of such limited areal units; that recurrent vertical uplifts can not explain such local dips with the observed arrangement; that the total lack of alignment precludes lateral crustal deformation; that the influence of compaction is at best wholly inadequate; that there is no evidence of sufficient solution to have produced the observed results; and that finally, when all the known factors are given due consideration, original deposition seems to be the most adequate explanation. The persistence of the "structures" upward is held not to be much greater than twice the height of the buried hill.

INTRODUCTION

Buried hills and the dips which they induce in superincumbent sediments have in the last few years become a very important item in

[1]Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, February 29, 1932. Published by permission of the Missouri Bureau of Geology and Mines.

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discussions of structural geology. It is doubtful whether any area has thus far been described, in which there is a better development of the significant phenomena of buried hills than in the St. Francois Mountains of southeast Missouri, an area quite properly considered the structural, though by no means the geographic, center of the Ozark dome. Equally important with the main St. Francois center is the closely adjacent, but quite distinct, area of the Eminence-Cardareva uplift. The particular importance of these regions results from several outstanding conditions, as follows: (1) the many individual, more or less isolated peaks on the old pre-Cambrian land; (2) the notable local relief on that surface, when the Cambrian seas advanced into the area, a relief whose average was approximately 1,500 feet, and whose maximum was probably not much less than 2,000 feet; (3) the fact that the peaks consist for the most part of extremely resistant pre-Cambrian rhyolite porphyry, in contrast to the easily eroded contiguous sediments, so that there has been developed a very sharp topography, as the adjacent covering has begun to be stripped away; (4) the fact that the peaks vary so greatly in their present degree of resurrection, from complete stripping to complete burial; (5) the fact that the overlapping sedimentary units are so thin, in comparison with the total relief, that several formations are brought into visible contact with the old hillsides. The relations thus become particularly obvious, even on maps.

The field work which resulted in the observations here presented was carried on for the Missouri Bureau of Geology and Mines. It was begun in 1922, and continued every summer until 1928. In the fall of that year, the annual excursion of the Kansas Geological Society was held in the Ozark area, and the writers were privileged to bring many of these items to the attention of that group, in the field. As there were many requests to have the observations published, and as the issuance of the contemplated areal reports would probably be considerably delayed, the Missouri Bureau of Geology and Mines consented to issue immediately a preliminary account, which appeared in time for distribution at the International Petroleum Exposition, that fall. In that article[1] the writers presented the more important of their observations, together with a brief statement of their interpretation of the facts.

The final detailed areal reports were published late in 1930, and

[1] C. L. Dake and Josiah Bridge, "Initial Dips Peripheral to Resurrected Hills," *Missouri Bur. Geol. and Mines 55th Biennial Rept.* (1928), Appendix 1.

became available for distribution in 1931.[1] Because, however, all of the articles mentioned have had a somewhat limited distribution, it has seemed worth while to present to the Association a summary of the observations and interpretations of the writers. For those who are interested in the study of detailed occurrences of the sort mentioned, and their presentation on published maps, reference is made to these detailed areal reports.

OBSERVED FACTS

Character of pre-Cambrian surface.—The areas to be considered consist for the most part of many hills of extremely resistant pre-Cambrian rhyolite porphyry, in part as ridge systems, in part as isolated knobs. In portions of the area, the buried hills are granite, but these are in general of much less relief. The intervening valleys are now floored with Cambrian sediments to depths varying from a thin veneer to nearly 1,000 feet. The older ridges rise to heights of 1,000 feet above the present valleys, indicating a pre-Cambrian relief averaging nearly 1,500 feet, when the Cambrian seas invaded the area.

Gasconade residual chert on many of the high peaks shows almost conclusively that most of the pre-Cambrian knobs were completely buried before the close of Gasconade time. Since then, the region has been repeatedly subject to erosion, and almost 1,000 feet of beds removed, leaving all formations from the Lamotte to the Gasconade now exposed, and all of them found in contact with the porphyry at various places. There seems to have been very little modification of the height, shape, or slopes of these knobs, since the cover of early Paleozoic beds has been stripped away.

Formations observed against the porphyry.—At many localities, heavy basal conglomerates, obviously derived almost wholly from the detritus of the porphyry itself, lap against the old slopes. This zone varies in age, transgressing time, as younger and younger horizons overlap onto the higher portions of the old land surface.

The oldest formation seen in contact with the porphyry is the upper part of the Lamotte sandstone of upper Cambrian age. This contact is extensively exposed. Where the coarser, locally derived conglomerates rest against the older slopes many of the dips are steep, not exceptionally 10°-15°. Where the Lamotte consists, as it does in many localities,

[1] C. L. Dake, "The Geology of the Potosi and Edge Hill Quadrangles;" and Josiah Bridge, "The Geology of the Eminence and Cardareva Quadrangles," *Missouri Bur. Geol. and Mines*, 2nd ser., Vols. 23 and 24 (1930).

of much purer sand, obviously brought in from distant sources, and not locally derived, the dips adjacent to the porphyry are much less steep, many being 4°-6°, and few exceeding 10°.

The next formation to lap against the pre-Cambrian peaks is the Bonneterre dolomite. It is not uniform in thickness, as a result of the overlap, but has an average of nearly 300 feet. Clay seams of more than 2 or 3 inches in thickness are rare, and aside from thin transition beds at the base, sandstone is not known in the formation.

In the Bonneterre, much steeper dips occur than in the Lamotte, 15°-20° being very common, and 25° having been measured at several places.

The Davis, the next formation to overlap the old floor, has a maximum thickness of not more than 200 feet. Locally it contains as much as one-third shale, but in general contains a much larger proportion of limestone, especially among the porphyry peaks, thus suggesting a foreign source for the Davis muds. In general, the formation has been widely removed by pre-Potosi erosion, in the areas among the old knobs, and few good contacts against the pre-Cambrian have been noted. Where they have been seen, dips are conspicuous.

The next unit of the sequence, the Derby-Doerun, is a somewhat argillaceous dolomitic limestone rarely reaching 100 feet in thickness. It has been even more widely removed by pre-Potosi erosion than the Davis, and at few places does it overlap beyond the older formation. Where it does occur adjacent to the porphyry, conspicuous dips were noted. The Davis and Derby-Doerun do not crop out in the Eminence-Cardareva area, but there is some reason to believe that local remnants of at least the Davis may be found in the deeper basins around and between the knobs. The Doerun is considered by Ulrich to be the youngest formation of the Cambrian.

Next above the Derby-Doerun is the Potosi dolomite. Its normal thickness is between 250 and 300 feet, but it has been widely removed in the St. Francois uplift, by pre-Van Buren erosion, and as with the Davis and Derby-Doerun, relatively few contacts with the old land surface have been noted. Where such do occur, dips are conspicuous. The Potosi and the overlying Eminence are considered by Ulrich to be lower Ozarkian in age. In the reports by the present writers, they have been assigned to the upper Cambrian.

In the St. Francois area the next formation, the Eminence, has been even more widely removed than the Potosi, by the pre-Van Buren erosion, and at very few places is it exposed, adjacent to the porphyry.

FIG. 1.—Initial dip. Bluff of Eminence dolomite on west side of Current River, showing steep dips found where dolomites come in contact with porphyry hills. Cave at extreme right of picture marks contact of dolomite and porphyry; hillside below it is part of porphyry knob. Note sudden increase in amount of dip in vicinity of porphyry. Bluff is about 350 feet high. Courtesy Missouri Bureau Geology and Mines.

In the Eminence-Cardareva region, however, where its average thickness is more than 200 feet, there are many such contacts showing remarkable development of conspicuous peripheral dips (Fig. 1), many of those observed being as steep as 25° and some being 30°. In both the Potosi and Eminence formations, sandstones and shales are notably lacking.

The next younger formation, the Van Buren, rests unconformably on the Eminence, and in the St. Francois Mountains, widely laps across all the older sediments down to the Bonneterre. At only one place, found in the Cardareva region, is it known to contain conglomerates of the porphyry, but at many places it rides over the old knobs at high angles. This is shown especially well by the conspicuous dip slopes of its basal sandstone, the Gunter member, which are particularly well suited to show this feature.

In the St. Francois mountain area, the Gasconade formation, the next in the sequence, does not crop out, but is widely represented by a deep mantle of residual chert float which at many points laps against the upper slopes of the old pre-Cambrian hills, indicating that this formation once widely overlapped the porphyry knobs. The position of the chert float gives undoubted evidence that this formation also was characterized by the same steep dips observed in the older formations adjacent to the old peaks. The Van Buren and Gasconade formations are considered by Ulrich to belong to his upper Ozarkian, but the writers have, in their areal reports, assigned them to the lower Ordovician. The Gasconade is the youngest formation to crop out extensively against, or in close proximity to, the formerly buried hills. In a few places, dips have been noted in the Roubidoux, though that formation has not been seen in actual contact with the porphyry.

Relation of sediments to porphyry.—The sediments are clearly younger than the igneous basement, for at literally hundreds of localities, basal conglomerates of water-worn porphyry pebbles occur in the overlapping strata. The present relief in the area is nearly 1,000 feet, from the tops of the higher porphyry mountains to the bottoms of the intervening valleys floored with Cambrian beds. Many of the high porphyry knobs have prominent sedimentary spurs, so that it is not uncommon, on the flanks of a single mountain, to see several formations in successive overlap against the old pre-Cambrian slope.

Amount of dip.—The amount of dip in the beds flanking the old topographic slopes varies appreciably with the nature of the overlapping sediment. In the coarse conglomeratic beds, each of which is clearly

derived from the residuum of the slopes against which it lies, dips are somewhat steep, as might be expected, 10°-15° being fairly common. On the contrary, in the typical Lamotte sandstone, which is quite pure, and much of which is obviously introduced from more distant sources, lower dips are the rule, 4°-5° being common, but 10° being decidedly exceptional. It should be noted, in this connection, that where the Lamotte sandstone laps against the base of high knobs, it consists largely of locally derived conglomerates and grits. This is true even of the porphyry knobs, but much more so where the old hills consist of granite. On the contrary, in the lower knobs not capable of actively yielding local material, the purer sandstones are in direct contact with the porphyry. This results in lower dips, since it is not possible for waves and currents to drift sands from outside sources up any but gentle slopes, perhaps comparable with those up which waves drift sand on modern beaches.

Unfortunately, the shales of the Davis were seen against the igneous peaks at very few places. Where they are heavily conglomeratic, dips are conspicuous, but where the material is nearly pure shale brought in from distant sources, the dips are not strong.

The most conspicuous dips, however, are developed in the dolomites. In the St. Francois mountain area the Bonneterre is most commonly in contact with the porphyry, but in the Eminence region the Eminence formation has this relationship. Therefore it is in these two that we find the most numerous and most striking examples of peripheral dips. Angles of 10°-20° are common (Fig. 1), 25° is not exceptional, and 30° has been measured.

Although very steep dips occur in the dolomites immediately adjacent to the old porphyry slopes, they flatten in short distances, and it is rare to find that the average in a mile of distance is more than 4° or 5°.

The dips are invariably less steep than the buried porphyry slopes against which they lap. In this connection it should be noted that in some places, where the porphyry slopes are exceptionally steep, the bordering dips are inconspicuous, as though the old topography were too steep to make possible the retention of sediments as they accumulated. So far as the writers are aware, no evidence has been found of contemporaneous crumpling from landsliding during deposition on the porphyry slopes. It is interesting, however, to note that on the pre-Pennsylvanian erosion surface around Rolla, on which steep hills, with a local relief of more than 150 feet, have been described, there is clear

evidence of contemporaneous landsliding, with the production of peculiar sharp local crumpling.

Magnitude of structural relief.—Since several formations are found in contact with the porphyry knobs, and since some of the contacts are easily traced, it is not hard to work out the structural relief, that is, the amount that a given contact changes in elevation, with approach to the porphyry. Changes from 100 to 200 feet are common, and several changes of 300 feet per mile have been measured. One change is known of nearly 400 feet in a distance of about 1¼ miles. This feature is particularly conspicuous in the area of the Eminence-Cardareva uplift, where the presence of the Gunter sandstone, the thin basal member of the Van Buren, affords an especially fine development of dip slopes. Here it is possible in many places to walk up a single bed through a vertical distance of as much as 100 feet, and in one place 300 feet. In this particular place the presence of residual Eminence on the summit of the knob, 100 feet above the highest sandstone outcrop, proves that the zone of the Gunter, though not necessarily the sandstone itself, was formerly at least 100 feet higher.

An inspection of the structure contour map of the Eminence and Cardareva quadrangles (Fig. 2) indicates that, if greater distances are considered, the amount of structural relief is even higher. In making this map, it has been assumed that the zone represented by the Gunter sandstone, the basal bed of the Van Buren, and the key horizon on which the contours have been drawn, passed entirely over the tops of many of the porphyry knobs. The basis for this belief involves the following facts: (1) the Gunter zone, even in close proximity to the porphyry, shows at only one place any detrital igneous material; (2) the sandstone itself may be traced as far as 200 feet, and in one place 300 feet up the sides of the knobs without coming into contact with the porphyry, and in all such places if the observed dips are projected upward the zone clears the knobs entirely, even if due allowance is made for the decrease in the amount of dip, as a horizon passes over the top of the structure; and (3) on some of the very highest knobs residual cherts of the Eminence, the formation next below the Gunter zone, are found, indicating that the horizon of the Gunter passed entirely above the knobs, though it is not known whether it carried sandstone at these higher elevations. More probably the sand zone had thinned out and may have disappeared entirely, since in several places its highest observed outcrops are very inconspicuous. By use of this map, it will be seen that some of these domes caused by the buried hills have a definite

FIG. 2.—Structure contour map of Eminence-Cardareva quadrangles drawn on top of Gunter sandstone. Each square = 1 mile. Contour interval, 50 feet. Latitude at top of map is 37°15′; at bottom of map, 37°. Longitude at west edge of map is 91°30′. Courtesy Missouri Bureau Geology and Mines.

local closure of 500 feet or more, and a maximum vertical element of nearly 700 or 800 feet.

Since the dips are in most places steeper than the present topographic slopes, it is commonly true that in ascending the valleys toward the pre-Cambrian knobs the normal sequence is reversed, successively older rather than younger beds being encountered, the older beds occupying higher positions close to the porphyry than the younger do in the intervening valleys. In the St. Francois Mountains, there are many places where one can climb from valleys floored with Davis onto spurs composed of the older Bonneterre, and thence onto the main peak of porphyry, although in the Eminence-Cardareva region the Eminence is found in many places flooring the valleys, and the Potosi occurs on the spurs, adjacent to the main peaks.

Evidence suggesting knobs yet buried.—So widespread, in this region, is the relation between height of sedimentary contact and proximity of porphyry, that in many places where a contact was observed at an elevation much higher than in immediately adjacent areas, a very careful search has shown the presence of small porphyry outcrops in valley heads, where they would otherwise have escaped notice. In a few similar places, no outcrop of the old knob was found, but the occurrence of porphyry float indicated its presence. In another place such dips were suggestive, and later it was found that a well 40 feet deep had its bottom on the igneous rock.

In other places, buried peaks have been strongly suspected, but no direct evidence could be secured. In one of these, near Bixby, in western Iron County, a magnetic survey showed positively the presence of the igneous knob at a comparatively shallow depth. The magnetometer also suggests other buried knobs at various points, though the evidence is less striking.

Lack of alignment of dips.—The most careful search, throughout the entire area, shows definitely that there is no hint of alignment in the dips adjacent to the old knobs.

In the isolated peaks the dips are definitely radial or quaquaversal. In those areas where the pre-Cambrian igneous rock makes up the major part of the region, the relations are particularly interesting. An especially striking example is in the southeast part of the Edge Hill Quadrangle, in what is known as the Tom Sauk region. Here, there is a definitely dendritic valley system in the igneous mass. That this system, with its primary, secondary, and even tertiary branchings, dates back to pre-Cambrian time is amply evidenced by the fact that all the valley

floors are occupied by Cambrian sediments. In all places, the strata dip toward the axis of the valley from both sides, and this is as true of the smallest secondary or tertiary tributary as of the main valley, and applies to every bend and turn of the valley sides. Similar examples occur in other parts of the two areas.

INTERPRETATION

Origin of dips.—There are several conditions which might account for domal effects such as those noted bordering cores of the porphyry. Some of these may be dismissed with very little discussion, others merit most serious consideration. Those which have been suggested are: (1) intrusive doming; (2) isostatic adjustment; (3) recurrent vertical uplifts; (4) lateral crustal deformation; (5) compacting of the sediments; (6) settling resulting from solution; and (7) initial or depositional dips.

Intrusive doming.—Laccolithic intrusion, of course, produces dips peripheral to igneous cores, but in the area under consideration, the igneous knobs are definitely older than the adjacent sediments, as proved by the occurrence, in every place, of basal conglomerates in which the chief material is the detritus from the older porphyry. No further argument is needed to show conclusively that intrusion of the visible igneous rocks is not the cause of the doming. The possibility of vertical uplift from deep-seated intrusions of younger age not yet exposed, is considered on a later page.

Isostatic adjustment.—From the very nature of the case, proof or disproof of isostatic adjustment is practically impossible. However, in the domes, many of which are not more than 100 or 200 yards across, and few of which exceed a score of miles, and in rocks as resistant to deformation as the porphyry basement, which is presumably many thousand feet thick, and which underlies the basins themselves at no great depth, such movement seems not only improbable but actually absurd. And this absurdity is greatly emphasized, when it is pointed out that the sediment in the intervening basins is in few places if anywhere more than 1,000 feet thick, and in many places not more than 100 or 200 feet; and further, that the peaks consist of rocks which are of practically no less density than those of the depressed areas between. Actual determinations show that the less porous parts of the Bonneterre have a density of 2.74, whereas the red phase of the rhyolite is 2.69 and the black phase 2.79. If the porosity of the sediment is considered, the actual weight per unit volume of the rhyolite hills seems to be somewhat more than that of the sediments in the intervening lowlands.

The true isostasist deals with blocks whose magnitude is measured in hundreds of miles, not in tens. Moreover, it should be noted that the dips marginal to the largest hills, and even to the periphery of the entire area, are no more intense than those fringing the smallest of the local knobs. Even the most ardent proponents of isostasy would hardly favor the view that it could be effective on such extremely limited areas, especially under the conditions noted.

Recurrent uplift.—It has been suggested that recurrent vertical uplifts, from causes other than isostatic adjustment, might play a part in the dips noticed in the area. Such uplift might result from deep-seated intrusions more recent than the pre-Cambrian rhyolites and granites, the bodies nowhere as yet uncovered by erosion. Or it is conceivable that other causes might operate, though they seem to be very obscure.

With reference to this suggestion, it must be pointed out that such deep-seated uplifts could hardly apply to the very small domes, the same objection urged against isostasy. And that they did not greatly modify the structure as a whole, even along the periphery of the major uplifts, is amply evidenced by the fact that the dips in the outer zone are no more striking than those around the smallest local porphyry hill. This, of course, applies only to the dominant "structures" of the St. Francois and Eminence-Cardareva regions, and not to the outward dips of the Ozark uplift as a whole.

Another point of great importance is that such vertical uplifts could not, by any means, be assumed to produce structure so closely simulating a pattern of dendritic drainage as do many of these troughs. To the writers, these facts seem to afford sufficient proof that uplift is not a significant factor in the "structures" observed.

Lateral crustal deformation.—Folds produced by lateral crustal deformation are normally developed in definite systems and show definite major trends. As has already been pointed out, the dips noted in the areas under consideration are as completely lacking in alignment as could well be possible. Where they are related to a single more or less isolated porphyry peak, they are obviously quaquaversal. If there happens to be a pre-Cambrian gorge in some part of the old hill, the radial character of the dip is locally modified or diverted, to correspond with the slopes of the irregularity.

In the area in which the porphyry crops out more extensively, the old pre-Cambrian dendritic drainage pattern is floored with Cambrian beds which dip from both sides toward the axis of the valley. This is

as true for the tributaries and sub-tributaries as for the main valleys, regardless of their trend. Every slight local change in direction of the valley wall is matched by a corresponding swing in the dipping beds.

It is wholly inconceivable that any sort of compressive forces could produce a series of folds in which the directions of major axes would be so widely variable, and would simulate so exactly a pattern of dendritic drainage. And as none of these directions of dip is appreciably more conspicuous than any other, it seems wholly improbable that any one of them has been materially modified or intensified by later crustal deformation.

The fact that definitely aligned folds are wholly lacking in the adjacent regions of sedimentary rocks, and that steep dips are practically unknown, except in contact with the porphyry, is also indicative of some origin other than ordinary compressive forces.

A further fact of considerable significance, showing that the domal effects observed are not true deformation, is that successively younger and younger beds overlap the higher slopes of the old knobs, indicating clearly that they were true hills of great height prior to the deposition, and were not domed up after the beds were deposited across them.

Compacting of sediments.—Several earlier students of the subject have suggested[1] that the compacting of newly deposited sediments around hills of older already completely consolidated rock was probably an important factor in such dips. In any adequate discussion of this subject, separate consideration must be given to the degree of volume shrinkage due to compacting in each different kind of sediment.

In the coarse basal conglomerates which border the porphyry at many localities in the heart of the St. Francois uplift, and in which dips as steep as 10°-15° are common, nearly all will probably agree that the process of compaction is wholly insignificant. Similarly in the purer silicious sandstones of the Lamotte, in which dips of 2°-6° are common, compacting could certainly not be an important factor.

It is in shales that such volume shrinkage has commonly been considered to be an especially significant factor. Miser[2] has concluded, from the distortion of spherical algae in the Cason shale, that that formation

[1]Eliot Blackwelder, "The Origin of the Central Kansas Oil Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 4, No. 1 (1920), p. 89.
M. G. Mehl, "The Influence of Differential Compression in the Attitude of Bedded Rocks," *Science*, Vol. 51 (1920).
Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Econ. Geol.*, Vol. 17, No. 4 (1922). See also other papers by Powers.

[2]H. D. Miser, "*Jour. Washington Acad. Sci.*, Vol. 21, No. 20 (December 4, 1931).

"has been compacted to about one-third of its original thickness." Mehl[1] has suggested a shrinkage of about 20 per cent, and Hedberg[2] has proposed a figure as great as 40 per cent. The only shale of importance in the area under consideration is the Davis. In the St. Francois region, the steepest and most conspicuous dips occur chiefly in the Bonneterre dolomite, which underlies that formation, and in which compacting of the Davis could therefore play no part whatever. In the Eminence area, the chief dips occur in the younger Eminence dolomite, it is true, but in this region, the Davis is wholly lacking, at least on the outcrop, as a result of pre-Potosi unconformity. There is, therefore, in the St. Francois Mountains no important shale which could be assumed under even the most favorable conditions to have any part whatever in the formation of the steepest and most plentiful dips, and in the Eminence region none is definitely known, though there may be a little in the centers of the deeper basins.

In view of these facts, there remains to be considered as a possible item of compaction, only that which could take place in the dolomites.

Very little is really known about the degree of volume shrinkage resulting during the lithification of limestone. Few estimates of its magnitude have been made. That of five per cent by Blackwelder[3] is the only one available to the writers, and is itself probably only a speculation unsupported by quantitative evidence. However, it is a well known fact that many fossils in shale are greatly distorted by compacting, whereas such distortion is very rare in limestone. The writers have seen spherical algae in the upper part of the Wilberns formation of Texas and in the Derby-Doerun beds of Missouri, in which the original sphericity has not been measurably modified by compacting, though they have doubtless in both places been as deeply buried as any of the beds involved in this study. The shales below the large cryptozoön reef masses of the Wilberns show considerable compacting, though the reef masses themselves indicate no such deformation. This would seem to indicate that Blackwelder's figure is probably sufficiently large. It is interesting, however, to apply this figure to the dips of the area under consideration. In the Eminence-Cardareva region, the most conspicuous and steepest dips, as already noted, occur in the Eminence dolo-

[1]M. G. Mehl, *op. cit.*

[2]H. D. Hedberg, "Effect of Gravitational Compacting on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (November, 1926), p. 1035.

[3]Eliot Blackwelder, *op. cit.*

mite. In the basins between the porphyry ridges, the average thickness of the sediments below the top of the Eminence in few places exceeds 900 feet, and is commonly much less.

Use of Blackwelder's figure of 5 per cent for compaction would result in a shortening of the column of sediments of less than 50 feet, and would produce a structural relief on the top of the Eminence of less than that figure, whereas the observed vertical element in the structure is not uncommonly more than 500 feet. It is therefore obvious that some other factor must be sought than simple compacting, unless Blackwelder's figure is far too low.

If the same figure is applied in the St. Francois Mountains, similar striking results are obtained. Here the major dips are in the Bonneterre, and structural relief on the top of that formation is commonly more than 300 feet, and probably reaches at least 500 feet. The total thickness of sediment in the bottoms of the intervening basins is in many places little more than 500 feet, and nearly one-third of that is sandstone in which compacting is surely much less than the estimated amount in dolomite. However, if all of it is computed as dolomite, the thinning of the column would not exceed 30 feet, and if allowance is made for the known proportion of sandstone, probably not more than 20 feet.

In a very few places, the vertical relief can be shown to be close to 100 feet, with actually less than 100 feet of thickness of dolomite above the porphyry floor.

Even if allowance is made for as much compacting in limestones as Hedberg[1] has assumed for shales, that is, 40 per cent, an estimate that is probably excessive, the shortening of the column in the Eminence area is still not more than 600 feet, which does not reach the maximum observed structural relief of the area. And this, according to Hedberg's estimates, would demand an overburden of 7,000 feet of sediments, a thickness probably much in excess of that ever present in this area. In the St. Francois region, where 100 feet of structural relief has been observed with less than 100 feet of thickness of total strata above the porphyry, even 40 per cent of thinning is wholly inadequate to produce the existing conditions. Practically all students of the subject, it is confidently believed, would agree that 40 per cent of shrinkage is far too high an estimate for dolomites. It is therefore obvious that no reasonable assumption in regard to amount of compacting can by any possibility explain the observed conditions.

[1]H. D. Hedberg, *op. cit.*

Naturally, however, it must be admitted that compacting may have in some degree accentuated the observed dips.

Thinning by solution.—Folded structure produced by solution is strikingly developed in many areas of the Ozark region. The characteristics of such structure have been summarized by Mather.[1] It is therefore pertinent to determine what percentage of thinning may be expected from this process. Stockdale[2] has investigated this subject at length, and concludes that as much as 40 per cent of thinning may result, as indicated by the extensive development of styloliths. He believes, further, that many of the numerous clay partings in limestones may be concentrated residues from solution, rather than original clay deposits.

As styloliths are almost wholly lacking in this area, they can not be used as a basis of estimate. Clay seams are present though certainly not plentiful in the rocks of the area, and are ordinarily very thin. Such clay partings as are found almost invariably show true sedimentary lamination, a condition which Stockdale points out is not true for solution concentrates.

One of the most common field evidences of active solution is the presence of many sink holes. In the Bonneterre formation, which crops out widely, sinks are exceptionally scarce, and this suggests that solution has probably not been extensively active in that horizon.

In the Eminence formation, which is a conspicuous chert former, active solution by surface waters, of sufficient magnitude to result in any great thinning of the dolomite, ought surely to result in the concentration of chert along the solution zones. In fact, at the surface, where the rocks are exposed to thoroughly aerated solutions, concentration of chert is widely observed. In mines, drill holes, and deep, steep valley cuts, on the contrary, there is very little evidence of such concentration in the less exposed parts of the formation.

It is generally believed that solution is much more active at and above the water table than below it, though a few students of the problem would question the validity of this belief. The deeper parts of these basins have for very long periods, in fact through much of their history, been below the water level, and if the foregoing assumption is true,

[1] K. F. Mather, "Superficial Dip of Marine Limestone Strata, a Factor in Petroleum Geology," *Econ. Geol.*, Vol. 13, No. 3 (1918), pp. 198-206.

[2] P. B. Stockdale, "The Stratigraphic Significance of Solution in Rocks," *Jour. Geol.*, Vol. 34, No. 5 (1926), pp. 399-414.

solution might not be expected to be very active in the deeper areas between the knobs.

Because of these facts, the writers fail to see any evidence of major thinning of the formations by solution. It is freely admitted that the observed dips may have been locally intensified by this agency, but the writers are firmly convinced that they were not in any considerable degree formed by, or for the most part greatly intensified by, that process.

Original dips.—One of the earliest references the writers have discovered to original dips peripheral to old hills is that by Taff,[1] where he describes those in the "Red Beds" of the Wichita Mountains. He says,

> The "Red Beds" have local variable but low dips away from the mountains, which were the old Permian land areas. These local structures are considered to be due to deposition of the sediments upon the sloping near-shore sea bottom rather than to be post-Permian orogenic movements.

More recently data have been accumulating which indicate that lime oozes are at present being laid down at considerable departures from horizontality. According to Field,[2] fine-grained lime oozes are now being deposited along the western margin of the Great Bahama Bank, on a sea floor that slopes 8° or 9°. There is evidence that the present floor represents considerable filling over the original bottom topography, and it is probable that the first deposits of the present blanket, where they are in contact with the original floor, are much steeper than the present slope would indicate.

Dips as steep as 30° and steeper were repeatedly observed by Cumings and Schrock[3] in limestones which lap against the flanks of fossil coral reefs. As the materials of the reefs and those of the abutting beds are of approximately the same composition, and of nearly the same age, there is little reason to believe that either differential compacting or differential solution had an excessive part in their origin, though it is realized that the conditions under which the actual reef and the border-

[1] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains of Indian Territory and Oklahoma," *U. S. Geol. Survey Prof. Paper 31* (1904), p. 72; also Pl. 8.

[2] R. M. Field, "The Great Bahama Bank, Studies in Marine Carbonate Sediments," *Amer. Jour. Sci.*, Vol. 16 (1928), pp. 239-46.
E. B. Bailey, L. W. Collet, and R. M. Field, "Paleozoic Submarine Landslips Near Quebec," *Jour. Geol.*, Vol. 36 (1928), p. 604.

[3] E. R. Cumings and R. R. Schrock, "Silurian Coral Reefs in Northern Indiana," *Proc. Indiana Acad. Sci.*, Vol. 36 (1926), pp. 71-85; "Niagaran Coral Reefs of Indiana and Adjacent States and Their Stratigraphic Relations," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 579-620. Also, K. F. Mather, *op. cit.*

ing beds were deposited might produce a difference in consistency which would result in a slight differential of compacting. Nevertheless, it is believed that these dips may safely be assumed to represent largely initial slopes of deposition.

In view of the fact that recent observations indicate certainly that lime oozes can be deposited at steep angles, it is pertinent to examine the dips in the limestones bordering the porphyry knobs of the Ozark region, to see whether the same origin may not safely be inferred for them.

To begin with, as already pointed out, the dips are wholly peripheral to the porphyry slopes, which have been shown beyond doubt to be purely topographic. Further, the dips are closely proportional to, but everywhere somewhat less than, the observed slopes of the underlying pre-Cambrian hills, unless these exceed 35°. If the hillsides are steeper than this, the abutting sediments show little or no dip, seemingly because on the steeper hills, sediments could not accumulate. This is strikingly shown at many places. For example, on a gentle porphyry slope, a contact may be traced far up the side, whereas, on an opposite steeper one, the contact rises little or not at all.

A few examples have been observed in which local elevated flats on the porphyry hills carry a thin cover of an older sediment, although the steeper slope between this flat and the base of the hill, too steep for the accumulation of the sediment, is definitely abutted by a younger formation at a lower elevation (Fig. 3).

One of the most difficult matters to explain is the way the Gunter sandstone, obviously derived from outside sources, rises against the porphyry slopes. Fossils in residual cherts prove that its horizon once passed over even the highest knobs of the Eminence area. It is not probable, however, that the sandstone itself ever rose to such heights, because it is clearly enough observed that the farther it is traced up the slopes, the thinner and less continuous it becomes. That it does now make prominent dip slopes, however, is clearly shown. To some degree, waves would drift it up such slopes, just as sand is now driven up sloping beaches. And it is not improbable that these slopes have been in some measure intensified by compacting and by solution.

The strongest argument in favor of compacting is the position of the Gunter sandstone, the dips of which are presumably to some degree intensified by such action. It is firmly believed, however, from the many facts already cited, that initial dip is by far the more important factor, and it is doubted whether compaction and solution combined can be the

cause for more than 100 or at a maximum 150 feet of the vertical relief of 500-800 feet.

The writers believe that the relationships of the dolomite and granite at Spavinaw, Oklahoma, represent a strictly analogous example. The outcrops are four peaks along a ridge trending a little east of north. The Cotter dolomite shows quaquaversal dips around each individual peak. The igneous rock itself exhibits abundant effects of hydrothermal alteration, but such alteration has not modified the adjacent sediments. The silicification which some have ascribed to contact metamorphism is

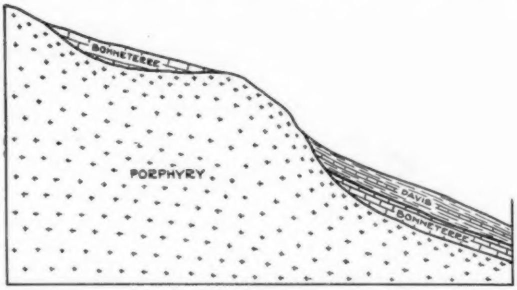

FIG. 3.—Sketch to show differences of sedimentation on elevated flat of porphyry hill and at base of hill abutting a steep slope.

simple secondary chertification, and can be observed in the same degree in literally hundreds of localities in Missouri and Arkansas, at great distances from known igneous rocks. Arkose has been reported at the contact. That conglomerate is not definitely visible at the surface is to be expected, when it is remembered that these outcrops represent the extreme top of a hill, swept nearly free from débris by the encroaching waves.

This occurrence represents the first stage in the uncovering of such a knob, a fact which can be more easily appreciated by one who has seen the much more completely exposed examples in the central Ozarks.

Favorable paleogeographic conditions.—Submergence sufficiently rapid so that the tops of many of the lower hills were completely under water before the valleys were filled with sediment, would permit deposition simultaneously over the entire knob at widely varying depths, so that contemporaneous beds would be deposited at proportionately varying elevations. Lime oozes, under such conditions, would collect on the slopes up to the maximum angle of repose, and the narrow and winding

character of the bays, and the numerous islands would prevent excessive wave action, and tend to favor retention on steep slopes. Even so, however, material would accumulate somewhat more rapidly in the intervening valleys, because of landsliding and removal from the hills by wave action, so that the beds would thicken toward the troughs, and dips and structural relief decrease on successively younger beds, conditions repeatedly observed in the area. The local absence of conglomerates on many of the steeper and more exposed slopes, and their excessive development in the more protected valley heads is certainly consistent with such conditions as those postulated.

The strongly embayed coast of Maine, submerged rapidly enough so that deep bays exist in close proximity to exposed rocky knobs, presents a somewhat close modern analogy to the topographic conditions believed to exist when these dips were being formed; except that there was no near-by extensive mainland, from which large amounts of clastic sediment could have been derived, in the Ozark area.

Persistence of structure upward.—As indicated, the thinning of the strata toward the hills, and the thickening toward the intervening basins, would result in the structure becoming less and less pronounced on successively younger beds. In so far as the "structures" have been actually exposed by subsequent erosion, this has been observed to be the fact. Unfortunately, however, no thick overlying beds passing completely across a "structure" are cut through by erosion, and little is actually known about the maximum thickness through which such dips may be reflected.

At West Eminence there is a well-defined dome with 200 feet of closure, in which no porphyry is exposed. A drill hole on the top of the dome is reported to have penetrated a thick series of limestones and entered sandstone at approximately 500 feet, without having encountered the igneous floor. The reports regarding the well are believed to be reliable, and indicate notable reflection through a considerable thickness of overlying strata.

The foregoing is the only direct bit of evidence available in the area regarding the upward persistence of these "structures." Because in other parts of the Ozark uplift, where sporadic drilling has indicated depths ranging from 1,000 to 2,000 feet for the old basement, local domes of the sort described are rare, one might assume that so great a thickness of beds had completely obliterated the doming effects. Unfortunately for the value of such an inference, practically nothing is known of the magnitude of the local pre-Cambrian relief, in the more

deeply buried areas. There is a suspicion, however, that it is probably less than in the St. Francois and Eminence-Cardareva uplifts. A study of the structure contour map of the Eminence-Cardareva region (Fig. 2) indicates that the dome effect is much less conspicuous in the eastern part of the area, where there is an additional cover whose average is nearly 300 feet in thickness. Whether the decrease in closure is wholly the result of increased burial or in part of less pre-Cambrian relief, is not known.

Several marked domal areas are actually known outside the main uplifts just described. Magnetic surveys have shown that the one at Bixby, in western Iron County, overlies a comparatively shallow knob of igneous rock, but the thickness of the cover is unknown. Concerning others, still less information is available.

If domes like those described in these pages anywhere persist through great distances of overlying rock, it is probable that it is only because other factors such as compacting and solution have served as active aids. There is some reason to believe that such hills would probably have to be buried to depths nearly twice their actual height before their effects would be completely obscured, but that beyond this depth there would be little probability of visible reflected structure, of purely initial origin.

Initial dips and unconformity.—An interesting relation has been noted between the types of domes herein described and the unconformities in the region. Seemingly emergence, even without warping, allowed

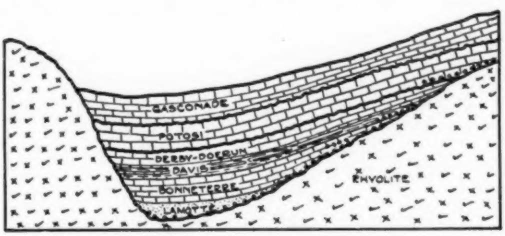

FIG. 4.—Sketch to show relation of dips in the sediments to steep and gentle porphyry slopes.

many of these "structures" to be truncated by erosion stratigraphically deeper than the adjacent troughs, and with submergence and influx of the next series of sediments the latter overlapped older beds at the center of the dome, with undoubted discordance of dips.[1] Whether

[1]See also K. F. Mather, *op. cit.*

conditions of this type should be termed angular unconformity, or whether the term should be reserved for conditions in which the discordance of beds is produced by actual deformation followed by erosion and subsequent deposition, may be open to dispute. In any event, there seem to have been produced relations essentially similar to angular unconformity.

SUMMARY

It has been the purpose of the writers to show that, in the particular area in question, in which shale comprises a negligible part of the section, the observed dips are largely initial, and to only a very minor degree the result of compaction and solution. It is not intended, however, to throw any doubt on the validity of compacting, as an important factor in similar domes, in areas where the character of the sediments is favorable. In fact, it is believed that in the Mid-Continent field, the remarkable upward persistence of many of the "structures" can only be explained on the basis of considerable compacting. The area studied, however, has been particularly favorable for emphasizing the importance of initial dip, and it is believed that the same type of initial dip is a larger factor in the domes of other areas than has heretofore been realized.

DISCUSSION

Luther H. White (Tulsa, Oklahoma): How do you explain the deposition of sand in several hundred feet of water, since you claim uplift has played a small part in the present attitude of the beds?

C. L. Dake: The extreme vertical range of the Gunter sandstone does not greatly exceed 300 feet, and the sandstone itself thins rapidly toward the higher portions, being largely replaced by limestone. Since the Gunter horizon occurs overlying the formations that show the extreme dips, it is to be presumed that by the time it was deposited, some of the embayed and protected character of the area had been eliminated, so that waves had a more powerful attack, and were able to drive sand up the slopes, much as sand is now driven up modern beaches. Though we have no quantitative data, it is known that sand is now drifted through a considerable vertical range.

However, we make no claim that compacting and solution have not been factors, and admit that these sandstone slopes have probably been increased by such agencies.

However, the steepest dips are in the thin edges of the sedimentary series, where compacting can not be other than a minor factor, and there seems to be no question that these striking dips are largely initial. The dips in the sandstone are less steep than those in the limestones.

We believe that a large part of the local structural relief is also initial, but that compacting has been an additional factor which has increased the vertical element of the structure.

Gradual regional uplift has probably been a considerable factor in the larger doming of the St. Francois mountain area, but it is almost certain that local uplift has had little or no part in the production of the local domes within the area.

John L. Rich (Cincinnati, Ohio): Among the interesting problems raised by Dr. Dake's paper is one of general importance, namely, that of the compaction of limestone. If limestones are formed on the ocean bottom as calcareous oozes, would not these oozes contain large percentages of water, so that in their later recrystallization they might compact more or less, in the manner of a shale?

Another problem is how it would be possible for a thin bed of sandstone such as Dr. Dake describes to be deposited on slopes outward from the knobs inasmuch as the sandstone came from an outside source. It would seem that the transportation of sand would require a considerable current, and it is difficult to see how the sand could be carried *up* to its present sloping position.

If the present dips are initial, it would seem that the materials must have been deposited in deep water below wave base, otherwise the lime oozes should have been leveled off and spread out by the waves.

C. L. Dake: To the first question, it may be answered that the most obvious indication that the compacting of the limestones has not been great, is the almost complete absence of distortion in the enclosed fossils. It should also be pointed out that the older series of rocks was completely lithified, and therefore most of the possible compacting in that portion of the section already accomplished, before the Gunter sand was laid down. The Gunter definitely carries basal conglomerates in which the pebbles are chert derived from the Eminence. From this fact, it becomes obvious that compacting in the underlying beds could play only a much less important part in the structure of the Gunter than would have been possible had the deposition of the sandstone immediately followed that of the underlying beds instead of being separated from it by an interval of the observed magnitude.

The second point has been considered at length in answering the question of Mr. White.

Concerning the third point, it should be said that we agree fully that the deposition of the series from the Bonneterre to the Eminence inclusive was probably in deep water, under protected conditions. At the close of the Eminence, however, the region emerged and was somewhat eroded. The presence of definite pebbles of the Eminence chert in the base of the Van Buren shows that the older formations were well lithified, and not subject to easy removal, when the basal sand of the Van Buren drifted in, and therefore it is not to be assumed that the area must have been below wave base, in Van Buren and Gasconade times. In these formations, dips are much less than in the older beds.

Frank C. Greene (Tulsa, Oklahoma): How was a succession of sandstone, dolomite, and sandstone, totaling 15 feet, deposited on a slope with a vertical relief of 300 feet, by wave action?

C. L. Dake: It should be said that the relations of sandstone and dolo-

mite in the Gunter are not everywhere the same, and that the horizon probably transgresses time, at least in some degree. It is also possible that a small proportion of the sandstone may be locally derived, though much of it must be from foreign sources.

While there appear to be difficulties in explaining the distribution of the Gunter sandstone, we believe the most serious difficulties have been met. In addition it seems to be indicated that difficulties regarding compacting or uplift are even less easily met, and seem to leave initial dip as the most plausible explanation of the major factors in the observed structure.

PAUL WEAVER (Houston, Texas): Does the sandstone on the flanks of the knobs show change of texture as it is observed farther from the edge of the porphyry?

C. L. DAKE: The change from coarse conglomerate obviously of local derivation, to pure limestone, or in some places to pure sandstone, almost certainly from more distant sources, is ordinarily somewhat abrupt.

ED. BLOESCH (Tulsa, Oklahoma): If the steep dips are initial they must show lower angles higher in the section and eventually disappear.

C. L. DAKE: The dips decrease rapidly away from the porphyry contact, both laterally and vertically, and this vertical decrease is one of the best evidences that the dips are largely initial.

A. F. CRIDER (Shreveport, Louisiana): Keyes[1] states that Devonian beds occur at the summit of the Ozark uplift in Missouri. "Summit" means the highest part of the uplift. Do the authors subscribe to the idea that the Devonian sea completely covered what is now the pre-Cambrian core of the Ozarks, or was the pre-Cambrian core a land mass during the Devonian period?

C. L. DAKE: Middle Devonian, of Grand Tower facies, has been discovered on the Ozark upland, at a single point near Rolla. So far as the authors are aware, no Devonian has ever been authentically reported from any part of the St. Francois mountain area, the true "summit" of the uplift. Whether the single outlier at Rolla represents a local embayment, or a general submergence in Middle Devonian time, is as yet wholly problematical. There is much more reason to suspect the general submergence of the pre-Cambrian core in Mississippian time.

[1] *Bull. Geol. Soc. Amer.*, Vol. 13, pp. 268-92.

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GEOLOGIC INTERPRETATIONS FROM ROTARY WELL CUTTINGS[1]

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ABSTRACT

The paper includes the history, improvement, and possibilities of geologic interpretation of strata in the Mid-Continent from rotary drill cuttings by the use of microscopy. The field technique with its certain advances in obtaining drill cuttings forms Part I. The laboratory technique of preparation, examination, and correlation of rotary drill cuttings forms Part II.

ACKNOWLEDGMENT

The writer wishes to express his gratitude to the Shell Petroleum Corporation for permission to publish this report and to the many drillers and sample-men who by their splendid coöperation and interest have contributed much to improve the methods and processes of handling rotary well cuttings, to the end of standardizing this technique in the Mid-Continent area.

INTRODUCTION

Rotary drilling equipment has gradually supplanted cable-tool equipment during the past 30 years because of the demand for safe and speedier completions of deep holes through soft "cavey" sediments. Its increasing use has stimulated constant improvement of methods of securing more accurate and detailed geologic and economic information.

HISTORY

Rotary drilling first came into popular use in 1901 with the development of the Spindletop field in Jefferson County, Texas. The first rotary drilling rig was designed for mobility. The early equipment could not operate to depths greater than 1,000 feet. Rotary equipment was improved from 1908 to 1910 so that wells could be drilled to 3,000 feet. Continued demand and improvement have resulted in wells being drilled deeper than 10,000 feet with rotary tools.

The rotary driller on the earlier wells interpreted the character of

[1]Read before the Association at the Oklahoma City meeting, March 25, 1932. Manuscript received, April 9, 1932.

[2]Geologist, Shell Petroleum Corporation.

the strata being penetrated by the action of the equipment (similar to the "feel" of cable tools) and reliance was placed entirely upon his experience. Cores were taken at a point where the pay sand was thought to be and, if sand was recovered, cable tools were rigged up for drilling in. Few exceptions to this procedure are reported because most conservation laws similar to Oklahoma's (modified in 1928 and 1929), specifically stated that cable tools should be used when drilling into producing sands. Deep wildcat wells were cored at arbitrary intervals, or whenever the rotary action indicated that sand was being penetrated. Systematic depth cores were later taken and paleontological determinations of stratigraphy were used with some success.

The Louisiana Geological Survey under direction of G. D. Harris in 1908-09 saved consistent sets of samples from 50 wells in the northwestern part of Louisiana. It is probable, however, that these were never examined and probably were destroyed when the Survey was abandoned in 1912.

C. W. Tomlinson, geologist for the Schermerhorn-Ardmore Oil Company, while working in the Graham field in Carter County, Oklahoma, in 1922, made attempts to obtain cuttings at each 5 to 20-foot interval, by catching the return mud in buckets at the end of the trough over the settling pit. These samples were washed, screened, and presumably arranged at the well in consecutive order for examination without the use of a microscope. Tomlinson, to our knowledge, is among the first who made attempts to obtain rotary cuttings samples in an orderly manner.

Few (if any) systematic sets of cuttings were consistently preserved for comparative reference until 1925, when several companies began the practice with the development of the Hubbard or Retta field in Kay County, Oklahoma. Prior to 1927, at only a very small percentage of rotary-drilled wells were cuttings samples saved above the depth of changing to cable tools, and probably at not more than 1 per cent of the rotary-drilled wells in the Mid-Continent area were consistent samples of cuttings saved from the surface to completion depth. The proportion of rotary wildcat wells represented by complete or nearly complete sets of samples increased to probably 40 per cent of the current operations from 1927 to the time of the Oklahoma City discovery in December, 1928. It is estimated that at least 75 per cent of rotary-drilled wells are represented by samples from 1,000 feet to completion depth, since the discovery of the Oklahoma City field. The practice of drilling-in with cable tools was abandoned in the early development of

this field, and all later wells were completed with rotary equipment, few being cored into the pay horizons.

The time of the drilling crew is fully occupied in the early stages of the drilling of a well on account of the rapidity with which the first 2,000 feet is drilled. Hence it is difficult for them to obtain samples. However, it is believed that with improved methods of catching samples, complete sets will be obtained from most of the wells drilled in the future.

Publications

Little has been published regarding rotary well cuttings. The first paper of public note was "Logging Wells Drilled by the Rotary Method,"[1] by Edgar Kraus, stressing the possibilities of improvement of the drillers' log by more intensive study of the action of equipment checked by examination of occasional samples taken from the return line.

The only other paper dealing exclusively with the subject was "Logging Rotary Wells from Drill Cuttings,"[2] by Stuart K. Clark, Jas. I. Daniels, and J. T. Richards, which covers collective experiments of the Marland Oil Company and the Gypsy Oil Company from 1925 to 1927. This paper showed that by proper application of certain methods of sampling, preparation, and examination, a decidedly improved and fairly satisfactory rotary log could be obtained. Present methods are fundamentally based on the outline of procedure suggested in that paper, and are supplemented by the many added features and refinements required for increasing accuracy and detailed information.

Considerations and Requirements

The accuracy of geologic determinations made from rotary-drill cuttings depends on two major factors: the samples and the examiner. The quality is of first importance in the samples. Experience and the faculty of keen observation are equally important requisites of the examiner. Speed in technique is essential, particularly in the Mid-Continent area, where keen competition between companies is prevalent.

The need for closer correlative horizons required for definite structural information and the demand for constant improvement of production methods and facts concerning ultimate recovery, require a more exact knowledge of the formations penetrated.

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (September-October, 1924), p. 641.

[2] *Ibid.*, Vol. 12, No. 1 (January, 1928), p. 59.

Lithology, because of its high percentage of recovery, is given primary consideration in rotary sample studies, while paleontology is considered secondary due to the limited number of fossils present in rotary cuttings. The knowledge of surface outcrop details and mechanical difficulties affecting the changes in quality of cuttings are essential to the examiner for a systematic and impartial interpretation of the rock cuttings. The conditions under which the cuttings were caught and prepared for examination are as important as the samples.

Part I. Field Operations

The importance of obtaining correct samples of the cuttings concurrently with the progress in depth in the well is apparent when considering the present and future value of every rotary sample log. Full and accurate information of the well can not be obtained when this sequence of samples is interrupted. Therefore, every precaution and care consistent with certain economy should enter into the catching, rinsing, sacking, drying, collection, and transportation of the cuttings from the well to the laboratory. Every one of these six operations has its direct bearing upon the question whether the log will be valuable or worthless.

Catching Samples

Samples consist of the cuttings suspended in the mud fluid returning from the bottom of the hole. The percentage of material from the strata penetrated during the interval which the sample represents is controlled by many things of which the proper catching of the sample is of first importance. Sampling methods should be judged on their ability to satisfy the following requirements.

1. Ability to make a continuous separation of a representative sample of the returns through a given interval
2. Accessibility or convenience
3. Adaptability to various rig arrangements
4. Ability to perform uninterrupted service
5. Economy and simplicity of installation

Certain devices, while not completely satisfying one or more of these requirements, may be entirely practical due to other desirable features which offset their disadvantages.

The four general sampling methods are the bucket, screen, mechanical, and settling methods.

Bucket method.—A bucketful of the fluid may be caught at the end of the return pipe as it empties the mud into the settling pit. This

method has gradually been discarded because the sequence of samples, instead of giving a true representation of all the rock penetrated, represents only a trace of the material actually cut at that depth mixed with more than 99 per cent caved and re-circulated material. This foreign content, if not represented in an upper sample, would be logged either

TABLE I

COMPARISON FOR SETTLING-METHOD SAMPLE CATCHERS

	Percentage of Importance	Wooden Boxes at Line Level	Weir in Flow Trough	Partition in Flow Trough	Circulating Type	Swedge with Gate	Swedge with Jet
				Per Cent			
Separation	50	75	5	20	75	45	100
Accessibility	25	45	10	20	60	30	100
Adaptability of installation	10	60	100	75	30	45	15
Service uninterruption	10	50	5	25	90	60	100
Economy of installation	5	75	100	90	30	45	15
NET COMPARATIVE VALUE	100	305	220	230	285	225	330
TOTAL PERCENTAGE OF EFFICIENCY		63.5	20.5	29.5	66.0	43.0	87.25

in error or not at all, due to inability to place it properly in the section. This method is already thoroughly discredited and will be entirely discarded in time.

Screen method.—The cuttings may be screened from the return mud fluid. Screens of innumerable sizes and shapes have been used in this method, all with unsatisfactory results due to bulkiness, mechanical and material weaknesses, and impossibility of cleaning. A further disadvantage lies in the fact that only the coarser cuttings are collected. The method was discarded altogether after many early experiments proved unsuccessful during 1926 and 1927.

These devices generally consist of a bag made from regular screen wire, some of these bags being reinforced with heavier hardware cloth. They are employed in some places where it is difficult to install other types of sample devices, and in particular cases where only a small amount of drilling is to be done they may be satisfactory. They are not recommended for general use, due to their small capacity, which does

not allow a representative sample to be caught. The mesh of the screen becomes clogged and instead of straining, it overflows as a filled bucket. Samples caught in a screen container can usually be identified by the large amount of soft rope and crater oil contained in them.

Mechanical method.—For the third method an attachment can be placed on the return line and connected with the "Kelly joint," so that automatically at 1-foot intervals a sample consisting of a small part of the returns passing through the device during the drilling of this interval is ejected into a separate container. Several of these automatic sample catchers have been constructed, but to date these have, without exception, proved unsatisfactory and short-lived, never having been used for more than a few hundred feet of any one well, because of mechanical difficulties which are unavoidable with the present operation of rotary equipment.

Settling method.—Weirs may be placed in the return pipe or discharge flume and a part of the returns diverted to a receptacle to settle out of the fluid. The application of this general method (with numerous variations ranging from simple to very complex) has become the most popular because of fairly consistent results. Figure 2 of Clark, Daniels, and Richards' paper[1] shows four different applications of this method to meet varying conditions at the well.

The important factors for consideration in using this—the settling method—are velocity and volume of return fluid at the point of collecting. The most probable effects are: (1) *high velocity and large volume* (box fills too rapidly for representative sample, allowing later cuttings to flow over the filled box); (2) *high velocity and small volume* (very coarse cuttings fill the box, due to agitation which allows the medium to fine cuttings to pass on with the fluid); (3) *low velocity and large volume* (a large, representative, well-graded sample); and (4) *low velocity and small volume* (a small but excellent representative sample).

There is no ideal arrangement which is flexible enough to meet every variation of conditions; therefore levels of collecting boxes, flumes, and diversion pipes or weirs should be checked at intervals to insure the best results.

All of the four illustrated common types of application of the settling method of catching samples, even if arranged to avoid most mechanical difficulties, must depend on the operator's removing the collected cuttings at regular footage intervals and cleaning out the box

[1] *Op. cit*, p. 65.

prior to the collection of the next sample. It has been a common practice in the past, under the influence of inclement weather, darkness, cold, lack of interest, and speed of drilling, for members of the crews to "make up" as many as 10 or 15 false samples (each supposed to represent a different 10-foot interval) from one collection in the box. This practice became so prevalent during the days of intensive development of pools, that geologists or extra men were placed at the wells for the purpose of properly collecting samples. Both of these practices were disconcerting to well owners, the former because of the falsity of the information and the latter because of increased costs. Eventually, drilling contracts included a clause obliging the contractor to furnish good and complete samples. Thus the responsibility of catching good and proper samples was placed upon the driller.

This resulted in marked improvement, but did not eliminate the main cause of poor samples, namely, conditions under which the sample was taken from the box. Members of the drilling crew were not inclined to coöperate with the driller and share in his responsibility. Therefore, of necessity drillers began devising equipment which could be attached inside the rig.

Two drillers, Jess J. Hood and R. D. McDaniel, drilling on a Sinclair Oil and Gas Company location in the Oklahoma City field for J. E. Mabee, contractor, in May, 1930, devised a sample catcher which, by the use of steam, jetted or ejected the sample into a bucket on the edge of the rig floor. Numerous improvements have slightly changed the design of the crude original model, but the idea remains the same. The samples from this catcher have proved very satisfactory and use of the device is becoming more widespread as a result of popular demand of both geological departments and drilling crews.

It is possible for the driller to catch samples at 1-foot intervals, when a jet sample catcher has been installed. The hot steam tends to dislodge the mud coating on the cuttings so that even from the wet samples a better knowledge of the rock penetrated can be obtained by the driller. The convenience of the device at all times has a marked effect upon the crew in promoting consistent and greater interest in improvement of rotary drilling. "Skips" or intervals of missing samples are almost unknown from wells where the jet catcher is used. The quality of samples caught depends wholly upon the previously outlined factors of velocity and volume of the return mud flow, together with the size and type of the weir in the return pipe in its relation to these factors.

Figure 1 shows the details of the improved-type jet sample catcher, and a new feature consisting of an attachment for the diverting weir.

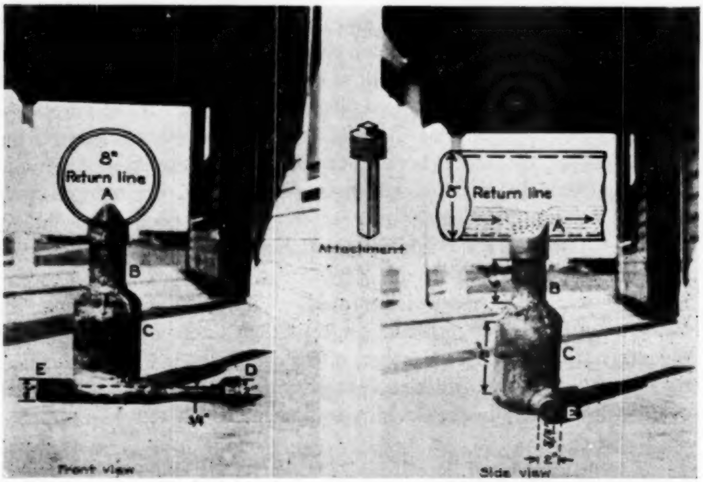

FIG. 1.—Improved-type jet sample catcher. Welded assembly is connected to 8-inch mud-fluid return line by flush-welding 3-inch collar into hole in under side of line. *A*. Lip on down-stream side of 3-inch collar. Projects into mud stream as baffle or weir, and constantly diverts or causes to settle part of cuttings in fluid. *B*. 3×6-inch nipple, through which cuttings settle into swedge below. *C*. 6×12-inch swedge, in which cuttings collect as they settle. Welded into down-stream bottom edge of *C* is 2-inch pipe which opens sideways into *C* and which also is swedged around a 3/4-inch pipe or jet. Jet at its inner end projects within 2-inch pipe to point well past farther side of swedge *C*. *D*. 3/4 × 2-inch reducer on outer end of jet pipe, connecting jet to steam-line. *E*. End of 2-inch pipe enclosing jet. This end connected to 2-inch line, called sample line, which runs to rig floor and there empties into baffle box shown on Figure 2. Principle of operation is that of steam-boiler water injector: high-pressure steam enters jet at *D*, rushes out of jet into 2-inch sample line near *E*, and siphoning cuttings collected in *C*, carries them up into baffle box on rig floor. Best results are obtained by jetting as each 2-foot interval is drilled. Similar catchers or traps can be made from standard fittings. Attachment is screwed into 3-inch-collar at a point centered above lip weir. It consists of a plug to which is butt-welded an angle-iron long enough to project to bottom of flow line in front of lip weir, with angle pointing down stream. Several plugs, each with different size angle-iron (1/2-2 inch) are used at various depths in accordance with drilling speed and volume of cuttings per cubic foot of return fluid. This attachment assures catching of cross section of suspended cuttings irrespective of variable depths of rock fragments in mud stream.

Figure 2 shows the details of the baffle box used with jet sample catcher.

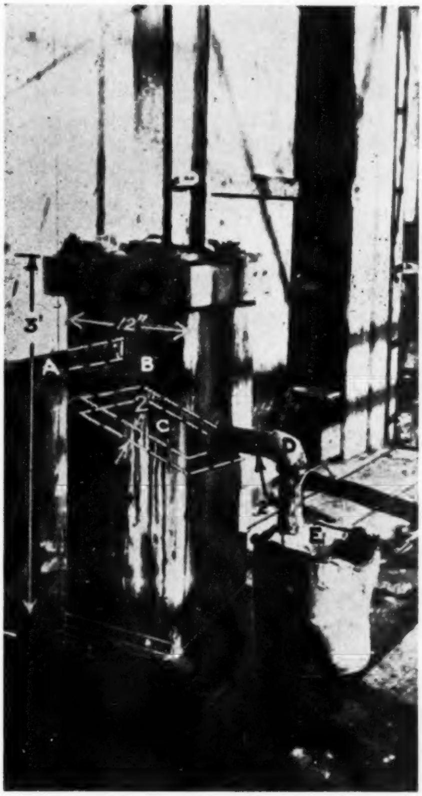

FIG. 2.—Baffle box used with jet sample catcher. *A*. 2-inch sample line from jet sample catcher, outside rig, entering baffle box located on rig floor. *B*. Expansion or ejection trap in baffle box, for release of steam pressure and precipitation of cuttings and mud-fluid. *C*. Inclined shelf, which catches cuttings and fluid and emits sample to discharge pipe. *D*. 2-inch discharge pipe. *E*. 60-mesh screen-bottomed bucket, for catching sample.

Figure 3 shows the details of the installation and connection of the jet sample catcher and baffle box.

I

II

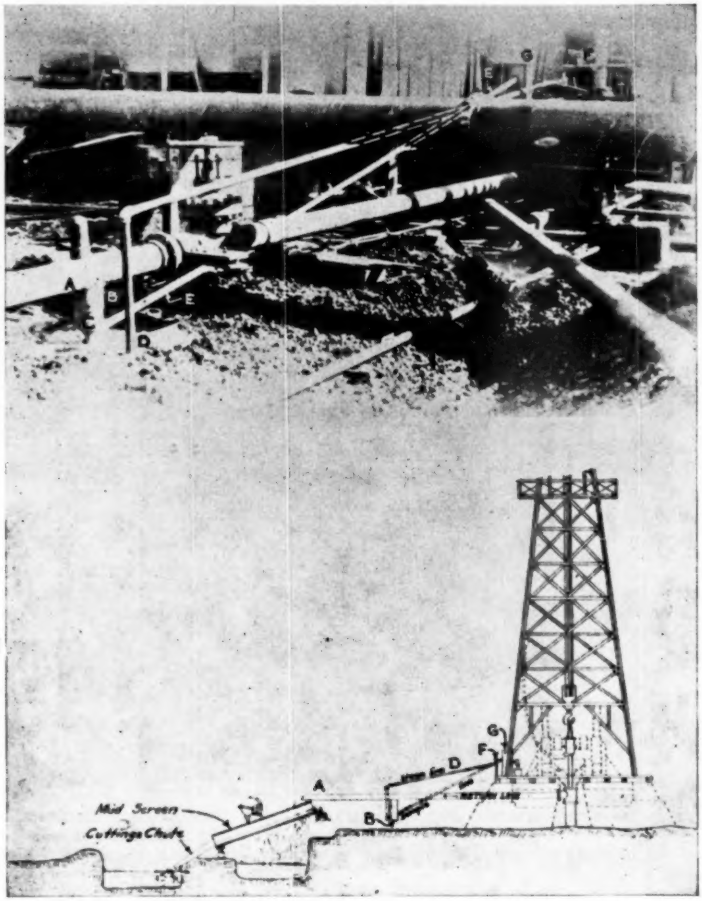

FIG. 3.—Installation and connection of jet sample catcher.

I. Exterior view at rig, showing mud-fluid return line, catcher, steam line, and sample line.

II. Sketch of rotary rig, showing installation of sample-catching equipment. *A*. Mud-fluid return line to pits. *B*. Sample-catching swedge, welded into fluid return line. *D*. Steam line, from control valve on rig floor to jet in base of swedge. *E*. Sample line, from swedge catcher to baffle box on rig floor. *F*. Driller's steam-control valve in rig. *G*. Baffle box on rig floor.

The settling of cuttings particles is dependent upon the ratio between the consistency and yielding point of the mud to the shape, size, and weight of the particle. Any particle smaller than the minimum size and weight required to shear a given mud does not have sufficient force in its contained area to liberate itself from the mud; therefore it can not settle out until the yielding point of the mud has been reduced.

The geologist's demand for more detailed and accurate information has resulted in the catching of samples from high levels and by more improved methods. Continued improvements in the methods and a thorough understanding of the importance of catching samples of all formations penetrated after setting the surface pipe should enlarge our geological knowledge in making determinations from rotary cuttings during the next few years. The practice of catching samples properly may be introduced as a method even in areas like California and Texas where Tertiary and Cretaceous formations are producing, to supplement the present coring practices of the operators. Many correct geological determinations have been made through the examination of rotary cuttings during the recent development of the East Texas field. The time consumed in catching these samples has been far less than would have been expended in coring formations for the same information.

RINSING SAMPLES

It is desirable that the cuttings be rinsed of the rotary mud or "slush" at the time of catching, because when first dried this coating, with the finer particles pulverized from the cuttings, forms an adhesive dust which is difficult to remove without considerable and careful washing.

The simpler processes of washing have their objectionable features. Time is consumed by necessary repetitions in the method where flushing, stirring, and decanting of the mud from cuttings in a closed-bottom bucket are used. Less time is used where a coarse-screening method (by punching holes in the bucket bottom) is tried, but the finer and important fragments are lost through the holes. Better recovery is obtained by wash-boxes bottomed with wire screen, but in these the finer screen soon wears out and becomes inefficient in saving the finer cuttings and micro-fossils. A more standardized and convenient adaptation of the screen-bottomed wash-box is a heavy galvanized iron bucket made with a reinforced 60-mesh screen bottom. The samples are caught in the bucket when ejected from the trap, a stream of clear water flowing at a moderate rate is introduced from a hose or pipe, and the sludge in the bucket is agitated slowly. The cuttings are clearly distinguishable and

full preservation of the sample is obtained. The introduction of hot water and wet steam in the later processes of rinsing in the screen-bottomed bucket has resulted in lessening the time consumed in separating the fluid mud from the cuttings. This latter application must be used with considerable discretion in rinsing the softer and more soluble sediments.

DRYING SAMPLE CUTTINGS AT WELL

It is important that all samples be dried at the well to prevent the possibilities of the moisture breaking down the structure of the softer and more soluble sediments. The sample of cuttings, after being washed and rinsed, is placed in a cloth bag, and is laid in the sun or hung at a definite place near the boilers to dry.

The cloth bag is usually the container in which the sample is transported and delivered to the laboratory, and by which the contained sample is protected and identified. A tag of cloth or heavy paper is sewed into a seam of the bag, and the identifying description of the well and its location and the exact depth interval represented by the sample are written on the tag. The sample is useless unless this definite and complete information accompanies the sample to the laboratory. It is also to preserve this information on the sample-bag tag that the newly sacked moist sample should be dried before it is transported from the well. The precaution is simple but essential.

COLLECTING SAMPLES

The dried samples "picked up" at the well should be carefully checked with the driller and his log, and notes made of all the information pertaining to any abnormalities of drilling—whipstocking, defective pump capacity, changes in circulation and weight of mud, increased or decreased weight on bit, and so on—that occurred during the interval which it represents.

CONCLUSION

Field operations pertaining to samples, although improved, have never kept pace with the progress in the laboratory, and many things, as explained, must be considered before the desired results can be obtained. Each operation must be understood by all concerned as vital to the ultimate value of any or all samples before the real significance can be comprehended. Further experimentation and research, together with full coöperation of every field man, should in the future produce more satisfactory results with a considerable reduction in the necessary

time and expense required for catching, rinsing, drying, and collecting rotary cuttings.

PART II. LABORATORY OPERATIONS

Laboratory operations comprise the work of the preparation of cuttings samples, the examination, the recording of derived information, and the reference-filing. Each laboratory, according to its requirements and customs, has some individual procedure to accomplish the desired end in these four operations, particularly in the last two operations which are not described in this paper.

PREPARATION OF SAMPLES

Laboratory preparation comprises the final washing, drying, and sacking of the sample of rotary cuttings before examination. Each sample must be handled in a slightly different manner throughout the processes of washing and drying. Care and consistency of procedure have important bearing upon ultimate results. An error in any one of the three processes may destroy the value of a good sample delivered through splendid field coöperation.

SAMPLE WASHING

The proper washing of a sample is accomplished by removing any rock dust or rotary mud adhering to the individual particles of the cuttings. The three common methods employed are: (1) boiling, (2) hand washing by the agitation and decantation process, and (3) mechanical washing in machines. Each method has its own peculiar advantages, but differs from the others considerably in the time required.

Boiling method.—This method was necessary with samples caught a few years ago when thorough rinsing was not done at the well. The method consists of placing a small quantity (6-8 cubic inches) of the sample in a metal container with enough water to cover to a depth of 1 inch on a stove or hot-plate. It is allowed to come to a boil, then is decanted, and the process is repeated until the boiling water no longer appears turbid. The water is then strained off and the vessel containing the wet sample is heated slowly to evaporate the excess moisture it contains. One man in an hour can label the necessary file sacks, properly wash and sack 10-15 samples and "cut out" an additional 30-45 sample portions of file size, by this method. The cleanliness, size, and character of the original sample controls the speed of work. Very soft sediments can not be boiled long or often, without causing disintegration of the cuttings.

Hand-washing method.—Hand washing consists of allowing the water pressure from a spigot to agitate and flush the rock dust or mud from the sample particles, the wash water being repeatedly decanted until it clears. This is still the popular method where mechanical washing machines are not used. It is used with poor success on samples consisting mostly of soft argillaceous material, for rock dust continues to form from such cuttings throughout agitation and can not be decanted thoroughly enough to prevent appreciable amounts remaining in the sample to coat the fragments when dried. Under these circumstances better success should be obtained by spreading the wet sample over a fine screen to drain and dry.

Mechanical-washing method.—Several machines have been designed for washing rotary cuttings by using either centrifugal, jigging, spraying, or tumbling action with water. The tumbling action has proven the most successful and popular, although a few companies retain spraying machines.

John E. Van Dall, geologist for the Sinclair Oil and Gas Company, designed, built, and patented a motor-driven machine using the tumbling action. The machine decreases the time required for the satisfactory washing of a large number of samples with a minimum amount of labor. Three to five minutes are required in each washing operation in which 16 samples are handled.

The superior success of this machine in comparison with others is due to the application of proper mechanical methods for the purpose intended. The machine has also been satisfactorily employed for other purposes, such as the extraction of micro-fossils from Tertiary and Cretaceous marls. The use of scalding water in the machine has in a short time entirely broken down the matrix and freed in an excellent state of preservation all micro-fossils contained in the sample. However, for this particular purpose it is suggested that minor changes in construction be made to permit rotating the sample under water at all times so that the water may act as a cushion for the very fragile forms such as *Foraminifera.*

DRYING SAMPLES

When the present methods are used, the proper drying of samples after washing consumes more time than any of the previously mentioned operations. The moisture which tends to be retained by capillarity in the collective particles of the samples must be evaporated as rapidly as possible without oxidizing or burning the rock material. Burning changes the color of most sediments, and also volatilizes any petroleum that may

be contained therein, hence two important geological criteria may be lost. When samples have been burned, the fact should always be noted on the sack for the information of the examiner. Hot-plates and ovens are the popular mediums of drying samples at present.

A safer and faster method would be one subjecting the wet cuttings to centrifugal force or a hot-air blast, but to date no satisfactory economical contrivance for this has been devised.

Agitation of the cuttings while drying is inadvisable due to the saturated cuttings causing rock dust or mud streaks upon the harder particles.

Thorough drying of a sample before placing in a gum-lapped paper sack is necessary, as the paper absorbs the moisture and soon develops breaks or cracks through which the finer material will be lost. Moisture may also cause mutilation of the data marked on the sack.

COOLING SAMPLES

If the samples are sacked before cooling, the paper sacks become partially charred or brittle, and are easily broken, allowing the samples to leak while being handled.

CUTTING OF SAMPLES

"Cutting" of samples in the laboratory eliminates delays attendant on field meetings, and avoids duplicate washing of equivalent samples by several companies. Washed samples can be better distributed into several equal file-size "cuts" containing the representative proportion of fossils and grades of coarseness of the cuttings.

Extreme care must be taken in "cutting" samples, to see that the proper samples are placed in the right sack. Systematic procedure usually accomplishes this objective without difficulty.

EXAMINATION OF SAMPLES

The geologic determination from a set of sample cuttings is concluded after many considerations and the application of several individual or collective methods by which there may be attained a true interpretation of the strata represented.

The specific purpose and the time allowed for making the determination have much to do with the methods to be applied.

The percentage of accuracy of determinations is essentially dependent upon the ability of the examiner to observe and interpret the details of the information contained in cuttings, and upon the com-

pleteness of the sample subsurface work already accomplished and available for reference.

EXAMINER

The scarcity of complete texts or manuals on microlithology and micropaleontology and of detailed lithologic descriptions of beds or formations, makes it necessary for the examiner to have had experience in detailed comparison of outcrops and with repetition of subsurface sections. He must also possess knowledge of correlative stratigraphy, structure, sedimentation, petrography, and micropaleontology. Many minor differences of opinion between examiners result from the differences between their respective ranges of observation and experience. Few examiners accustomed to determining only formational contacts are capable of noting the details of lithology and fossils which are essential for predictions not only of regional changes of sedimentation and unconformities, but also as to the economic value of certain horizons.

All examiners should have a complete understanding of the mechanics of rotary equipment, so that conditions affecting the quality of cuttings can be considered.

SAMPLES OF CUTTINGS

Table II shows that the four major factors to be considered in evaluating samples of rotary-drilled cuttings are: (1) quality, (2) quantity, (3) continuity, and (4) interval, of which the first has the most important bearing on the accuracy of a determination. The other three are also important, but deal more with the details of stratigraphy in a given area.

1. *Quality.*—Quality of samples is affected for the most part by (a) percentage of cavings or re-circulated material, (b) representative character of recovered cuttings, (c) size of particles, and (d) degree of cleanliness.

a. A sample of rotary cuttings containing less than 20 per cent of cavings or re-circulated material is considered as good workable quality. Constant comparison of percentages under similar conditions in many wells of an area has proved that most foreign material in a sample is due to caving rather than to re-circulation. The employment of mechanical shale-catchers or screens under the mud-fluid return line before the fluid is discharged into the settling pit, the proper leveling of baffles to reduce the gradient of flow in settling pits, more and larger pits, and constant jetting of coarse settled cuttings, have almost eliminated the re-circulation of coarse material and have substantially re-

duced maintenance expense on the mud pumps. Much caved or foreign material in the sample is usually caused by crooked hole, operations in straightening hole, shut-down of pumps, whipstocking, slow drilling, reaming, fishing, improper mud mixture, and excessive open hole.

TABLE II

EVALUATION CHART OF ROTARY-DRILLED CUTTINGS SAMPLES

Comparative Importance Percentage			*Importance Percentage*		*Comparative Value*
Quality	50	Represented character	60	Well proportioned separation	100
				Poorly proportioned separation	75
				Changing lithology	50
				Same lithology	10
		Degree of cleanliness	25	Clean particles	100
				Rock dust	50
				Crater oiled	25
				Mud pellets	10
		Per cent foreign material	15	Upper cavings	100
				Re-circulated	80
				Lower cavings	50
				Contaminated	10
		Size of particles	10	Medium	100
				Coarse	50
				Fine	50
				Super-fine	10
Continuity	25			Continuous	100
				Occasional "skip"	75
				Irregular depths	25
				Few samples	10
Interval	15			1-5 feet	100
				5-10 feet	90
				10-20 feet	50
				More than 20 feet	20
Quantity	10			Excess	100
				Average	90
				Few particles	25
				Piece	10

b. Proper catching of samples has the most to do with the truly representative lithologic and paleontologic characters of the cuttings saved, although pump capacities and weight of mud have much to do with the disproportionate settling of cuttings both in the hole and in the pits as theoretically outlined by L. G. E. Bignell.[1] However, Bignell

[1]L. G. E. Bignell, "Carrying Capacities of Mud Fluid," *Oil and Gas Jour.* (May 22, 1930).

has not given consideration to the suspending properties of certain muds. Soft friable porous oil sands—when very light mud or water was being used—have been penetrated to a depth of 25 feet before the first sample containing sand was caught almost 2 hours later, while extremely heavy mud sometimes re-circulated the sand by not allowing it to settle in the pit.

Each well must necessarily have its individual peculiarities caused by the combination of circumstances connected with each. Lag in arrival of cuttings at the surface seldom is calculated because all wells are drilled under similar general conditions and the comparative basis remains the same. Unusual circumstances, however, such as many and large cavities caused by caving in deep holes, should be considered for their effect upon velocity of the mud-fluid stream.

c. The method of catching samples and the weight of the mud usually determine the size of the particles in the cuttings recovered, although some variation is noted with the differences between drilling bits. Pump pressure and volume control the size of rock fragments, in that large pumps generally deliver coarse cuttings by immediately removing them from the bottom of the hole, whereas smaller pumps using the same mud have a tendency to allow the bit to mill the particles before removal. The sharpness of the bit and the time allowed on bottom have a material effect upon the size of the cuttings. Heavier muds usually produce coarse cuttings and cause much more re-circulation as well as retardation in drilling, which results in more frequent running in and out of the hole with the tools, causing caving. The size and depth of the hole also affect the size of the cuttings.

d. All rock dust and rotary mud should be removed from the cuttings before examination. "Crater oil" (heavy rock-bit lubricant), if not removed, tends to form small balls of the particles of cuttings, and in addition can be mistaken for an oil showing in porous sediments when tested with ether, or if charred in drying might give the appearance of plant remains, coal, or gilsonite.

2. *Quantity.*—The quantity of a sample of cuttings is important in that the variation of quality can sometimes be corrected only by using a larger quantity for examination. A larger quantity of cuttings should be examined to discover whether or not fossils are embedded in a matrix of the cuttings material if it is thought that cavings have been included in the cuttings. Sometimes large quantities of a sample are required to show the presence of important thin zones in deep holes. A sample containing 30 cubic centimeters of material is usually sufficient for ordinary work.

3. *Continuity.*—The success of determinations from rotary cuttings depends mainly upon the ability to observe the slightest lithologic and paleontologic change in the new material present in each successive sample, therefore it is readily apparent how "skips" or intervals of missing samples might cause considerable difficulty, if material from these unsampled intervals later caves into the hole when samples are being recovered from greater depths. An unbroken sequence of poorer quality samples is usually better than an interrupted set of good quality.

4. *Interval.*—The common practice is to obtain a sample of each 10 feet of rock drilled, although in the upper 1,000 feet, where the drilling is very rapid, 20-foot samples are sometimes taken, thus somewhat relieving the crew during the period of greater activity. Five-foot (or even smaller) intervals are sampled at important horizons and in thin producing strata. Few well-detailed logs can be made from samples of greater than 10-foot intervals. Cuttings from cored intervals in wells and from core-drill holes are obtained every five feet or less.

EXAMINATION

INTERPRETATION OF CUTTINGS

The examiner must observe the details of any new lithology or fauna appearing in each successive sample and learn to detect and correlate at a glance all previously penetrated material present in the sample due to either caving or re-circulation. The quality of the sample, as mentioned, is a direct function of the proportion of new material in each successive sample. No set rule can be given for reading the percentage of material actually penetrated contained in a sample, because of the variation in settling and size.

Some of the softer sediments, such as shale and gypsum, have a constant tendency to cave into the return mud fluid, but the percentage present in the sample is generally so small that only immediately following times of shut-down is the concentration sufficient to be mistaken for having been drilled during that interval.

Thin coals and carbonaceous shales, even though representing a small percentage of the sample, are readily distinguishable and their stratigraphic interpretation is known by the beds allied to this type of sedimentation. Certain faunal zones also show this relationship.

Only by very careful attention to details and the visualizing of certain processes of sedimentation is it possible to distinguish at any time the difference between very thin beds of limestone or dolomite and zones of concretions. Much careful study and reference are required when

the interpretation of this feature defines an important stratigraphic or economic structural horizon.

Many thick sand series are encountered whose individual beds or lenses can be determined only by the comparison of minute details such as size and shape of grains, purity, cement, and related physical features.

Important and valuable research steps can be accomplished while making routine examinations, such as preparation and filing of small lithologic and faunal slides, physical logs, and evidences of erosional unconformities. These references at times prove their value in the instruction of new examiners, and in studying comparisons with supposed correlative sections of unknown areas being explored.

Interpretative description.—A table of descriptions has proved satisfactory for most purposes, and consumes a minimum of time and space in its use (Table III).

TABLE III

SANDSTONES

Sizes: very fine, fine, medium, coarse, gravelly
Shapes: angular, sub-angular, rounded, sub-rounded
Assortments: even, uneven, conglomeratic
Colors: white, brown, red, gray, black
Textures: friable, porous, soft, hard, cemented, quartzitic
Compositions: gypsiferous, arkosic, quartzose
Cements: calcareous, siliceous, dolomitic, argillaceous, ferruginous
Drills up: free, in aggregates, in chunks
Surfaces: clear, etched, enlarged

LIMESTONES AND DOLOMITES

Colors: white, gray, brown, black, mottled
Crystallinities: dense, fine, medium, coarse
Textures: soft, hard, porous, flaky
Compositions: argillaceous, arenaceous, marly, dolomitic, cherty, siliceous

SHALES

Colors: white, gray, brown, black, variegated
Textures: dense, soft, hard, splintery, fissile
Structures: well laminated, non-laminated, massive, concretionary
Compositions: calcareous, siliceous, carbonaceous, arenaceous

"GYPSUMS"

Colors: white, gray, red
Structures: fibrous, granular, foliated
Compositions: selenitic, anhydrous (anhydrite)

COALS

Characteristics: brittle, lithohumic, lignitic

The colors red, brown, and gray are graded as light, medium, or dark or as mottled one to another. Sizes of sand grains and the crystallinity

of limestones and dolomites are also gradational into one another; for example: fine to medium-grained sand or dense to coarse crystalline limestone.

PURPOSE OF EXAMINATION

The examination of cuttings in the Mid-Continent area serves a threefold purpose: (1) the determination of subsurface contact points of formations or designated lithologic horizons for use only in subsurface structural mapping; (2) the determination of the economic character of horizons for use in the application of production methods and in dealing with water hazards; and (3) the interpretation of the stratigraphy for use in problems of regional structure, sedimentation, and petroleum accumulation. Sufficient time has not been allowed in the past for properly gleaning all the information contained in the cuttings from wildcat wells. It is suggested that the future reference value of each well be considered and that, during the examination, time be allowed for the description of certain details beyond the immediate purpose.

METHODS

Microscopy.—The dry method of examination is used exclusively, with a binocular microscope having a magnifying power ranging from 10 to 30 diameters. The sample is illuminated by concentrated artificial light generated by lamps of various types. Ordinarily, a magnification of only 10-30 diameters is sufficient to ascertain the rock structure. It also gives a greater field for the faster and better observance of the percentage of the kinds of material in a sample. It is necessary only in rare instances to submit the sample to natural light to determine the shades of color.

Chemistry.—Experience in observing rock crystallinity under a microscope soon teaches the examiner the difference between limestone and dolomite and the other materials commonly incorporated with them. In some cases, such as with the cementing material of a sandstone, it is necessary to check the presence of lime by its effervescence in hydrochloric acid, or even to use the silver nitrate-potassium dichromate stain test in the determination of dolomite. The siliceous residue test may occasionally prove of value.

It is at times necessary to submit the cuttings to an ether or acetone test, although most petroliferous zones are ordinarily recognized in their cuttings under the microscope. The flame test also is used in connection with some cuttings to determine certain material that may appear highly carbonaceous.

Mechanical classification.—Screen tests have proved successful with some samples, such as core-drill cuttings from the softer red sediments which contain many lenses of variable sandstones. This method consists of screening a definite quantity of each sample and recording the percentages of material according to size. The comparison of these percentages in several wells drilled under the same conditions has in some cases been sufficiently definite to admit of making correlations.

Paleontology.—Cuttings containing fossil fauna or flora are usually examined very successfully, and, even though the sequence of the lithology may designate the stratigraphic horizon, the fossil families or genera are recorded. All specimens of fauna and flora occurring at indefinite horizons, or from wells in areas where little is known of the stratigraphy, are recorded on the log and are removed from the sample. These forms are secured in file slides and are kept for future reference and detailed study of the variation, association, and range of species present in the rock section of the area. Certain paleontological research, as explained later, can be carried on in connection with routine examination.

Definite stratigraphic ranges have been delimited as existing for some few forms, and the first appearance of these forms in a set of cuttings is important in the determination of the geologic age of the rock penetrated.

Depositional environments have much to do with the presence of fauna or flora in a sample. Most fossil specimens occur embedded in fragments of the rock matrix of rotary cuttings; therefore faunal zones or horizons are easily ascertained if the sample is carefully examined.

ROUTINE RESEARCH

Lithologic.—Systematic file slides of the rock penetrated should be made for "wildcat" areas or in the development of new pools, so that by the detailed comparison of the physical rock rather than the usual comparison of interpretations on logs, a better and more complete understanding of the change in sedimentary environment may be obtained.

Paleontologic.—The constant practice of removing well-preserved fossils from the cuttings and mounting the individual forms in slides for detailed comparison with their generic associates from the outcrop has proved invaluable in developing major and minor differences in species for the determination of both vertical and horizontal ranges.

Improvement in the interpretation of rotary cuttings is directly proportional to the amount of routine reference research accomplished.

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GEOLOGY OF PART OF FINGER LAKES REGION, NEW YORK[1]

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ABSTRACT

The formations cropping out in the Keuka Lake and Seneca Lake area are fully described in detail and their areal distribution defined. Errors previously made in correlating the Devonian formations are corrected and changes in sedimentation described. The Barrington-Milo structure drawn on the Keuka flagstone and a stratigraphic section of the Devonian formations are presented.

LOCATION

The territory under consideration, comprising an area of approximately 215 square miles in the central part of New York state, consisting of Jerusalem, Torrey, Starkey, Milo, and Barrington townships, Yates County, and Pulteney Township, Steuben County, lies in the Penn Yan-Ovid quadrangles.

TOPOGRAPHY

The Devonian area, embracing portions of Keuka and Seneca lakes, consists primarily of rolling hills deeply dissected by gullies and ravines and by the drainage tributaries flowing toward the main lake bodies which lie in north-south synclinal valleys.

The western side of the area is the most irregular. Elevations above sea-level range from 709 feet at lake level in the broad valleys to 1,800 feet on the high hills. On the northeast the hills slope gently toward Seneca Lake, but on the southeast, end in an eastward facing escarpment or bluff. The drift sheet in many parts of the area is thick and completely obscures the underlying formations.

EARLIER INVESTIGATIONS AND ACKNOWLEDGMENTS

The geology of the area was originally investigated by D. D. Luther[3] and has been of interest geologically ever since.

[1]Manuscript received, March 12, 1932.

[2]Geologist and petroleum engineer.

[3]D. D. Luther, "Geology of the Penn Yan-Hammondsport Quadrangles," *New York State Mus. Bull. 101;* also "Geology of the Geneva-Ovid Quadrangles," *New York State Mus. Bull. 128.*

The writer was associated with C. E. Fralich during the summer of 1931 in detailing the structural effects in this area, and much credit is due him for his work in mapping and correlation.

STRATIGRAPHY

All of the exposed rocks in this area belong to the Devonian system, and much the greater part to the Portage group of the upper or Neodevonic division.

Previous to this investigation, geologists did not take full cognizance of the rôle played by structural deformation and sedimentary changes in the correlation of the Devonian section. Lying between the Ithaca group of the Portage on the east, and the Naples group on the west, the sedimentary changes in deposition of each group are present to a pronounced extent in this area. Negligence of these factors resulted in an error of correlation of such proportions as to call for revision of parts of the New York State geological report on this area.

The type columnar section, which is shown in Figure 1, was compiled from actual field tape measurements and well-log data.

The geologic formations of which the surface rocks in this area are composed, consist of the following, in descending order.

Era or System	*Period or Group*	*Stage or Age*
Neodevonic	Chautauquan	Prattsburg shale
	Portage	Highpoint sandstone West Hill flags and shales Grimes sandstone Hatch shales and flags Rhinestreet shales Cashaqua shales Middlesex shale Standish shale West River shales
	Seneca	Genundewa limestone Genesee shale Tully limestone
Mesodevonic	Hamilton	Moscow shale

Although nearly all of the formations of the Neodevonic system are exposed in this area, the higher members of the Portage group are exposed in so few places that it is impossible to follow possible horizons with any degree of accuracy.

The following discussion of formations is applicable to those formations necessary for an interpretation of the structural features of the area.

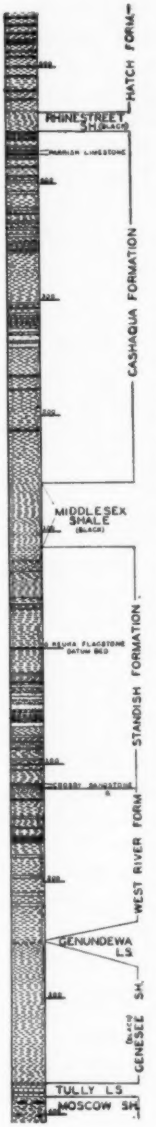


FIG. 1—Stratigraphic section. Scale in feet.

SURFACE STRATIGRAPHY

Moscow shale.—The lowest in the series of rock formations exposed in this area is the Moscow shale member of the Hamilton group, which is composed of soft light blue-gray calcareous shales. The lower part of the formation tends toward a light blue color. The upper part is inclined to be darker and at some contacts with the Tully limestone is almost black. Thin layers of limestone of limited lateral extent and calcareous lentils, composed principally of fossils, occur in many places in the shale. At Menteth Point, Canandaigua Lake, a persistent layer of limestone (Menteth limestone) about 1 foot thick and of some horizontal extent occurs at approximately 50 feet above the base of the shales.

Stratigraphically the Moscow shale overlies the Tichenor limestone, so called from its type locality exposure at Tichenor Point, Canandaigua Lake. Although a complete vertical section of the Moscow is not found in this area, a good outcrop is exposed in the gorge of Kershong Creek north of the area near Bellona.

The Moscow shale outcrops are limited in number, but may be seen along the Keuka Lake outlet between Seneca Mills and Seneca Lake and in Bruce's Gully on the south side of the outlet near Cascade Mills. A few outcrops displaying the upper beds occur between Dresden and Plum Point along the west shore of Seneca Lake, particularly at Perry Point and Pioneer Camp.

Tully limestone.—The Tully limestone, which succeeds the Moscow shale, is a very persistent, easily recognized formation. In central New York, from Smyrna, Chenango County, on the east, where it assumes the characteristics of the underlying Moscow shales, to Gorham, Ontario County, on the west, where it disappears by thinning out near the east shore of Canandaigua Lake, the Tully is an important stratigraphic datum plane. On the east, depositional changes in sedimentation cause a vast change in the lithology of the Tully by a thinning of the limestone and interbedding with sandstone and calcareous shales. On the west the Tully is represented by a stratum of limestone less than 3 feet thick cropping out southwest of Gorham near Canandaigua Lake. Westward the Tully horizon is represented by thin lentils of pyrite varying from a few feet in lateral extent to the length of the exposure.

The Tully limestone, which retains its true characteristics in the area investigated, consists of multiple layers of hard, bluish limestone, 11-15 feet thick, which on weathering tend to break into angular blocks

of a light gray color. Due to the extreme hardness of the Tully and its position succeeding the soft Moscow shale, cascades and falls are formed at almost all outcrops in the ravines.

The Tully limestone is almost devoid of fossils, but at some outcrops fossils are plentiful in one or several of the limestone layers.

The Tully crops out in many places along the outlet between Keuka Lake and Seneca Lake. The most westerly exposure at Seneca Mills forms a cascade 14 feet high at 602 feet above sea-level. Farther east, at Cascade Mills, an excellent exposure of Tully causes a cascade in the bed of the same stream. At Bruce's Gully it is 534 feet above sea-level, rising southward to 584 feet at the top of the Tully as exposed in the same ravine, thence eastward ¼ mile, where it is exposed at 580 feet above sea-level at the falls and then rises steadily southward along the stream bed.

Along Seneca Lake the Tully crops out in Perry Point ravine at 562 feet above sea-level 1 mile south of Dresden. Southward it is covered with drift and at Pioneer Camp it forms a falls at 527 feet above sea-level. In the succeeding gully ¼ mile farther south the Tully is not exposed, but the overlying Genesee black shale beds are found at 483 feet. As the Genesee beds are noticeably flat, all evidence points toward a fault with a displacement in excess of 43 feet. The Tully again crops out 1½ miles north of Plum Point at 491 feet and dips steadily southward for 1 mile, where it enters the lake at 444 feet above sea-level. The Tully is next observed just north of Plum Point, where it again enters the lake, dipping southward, and rises from the lake in a small arch ½ mile farther south. It continues at lake level for 1,000 feet and then rises in an anticline to a height of 27 feet above the lake level across Severne Point and on the north side of Miller Point, where with a dip of more than 2° southward it disappears below the water of Seneca Lake.

Genesee black shale.—The Genesee shale is one of the most easily recognized and persistent of the Devonian formations in New York and derives its name from its excellent exposure at its type locality in the Genesee River Valley.

The shale is densely black, bituminous, highly fissile, and on weathering develops angular joints and a reddish brown discoloration from decomposition of pyrite. A thin coating of alum is found on sheltered, weathered sections of the shale produced from decomposition of the pyrites. The outcrop, usually well eroded, develops bastion-like cliffs and steep step-like falls that are very distinctive. It contains few fossils,

but rows of irregular concretions are common, of which a few are found to contain liquid hydrocarbons. Numerous gas seeps are found in the black carbonaceous shale along the west shore of Seneca Lake, one in particular on the north side of Smith Point.

Well records give a good indication of the transitional thickness of the Genesee shale from west to east. It is approximately 190 feet thick on the western side of the area, decreases to 150 feet in the central part, and on the east is approximately 125 feet thick. Farther east the shale diminishes in thickness within a short distance and at its eastward outcrop in Chenango County is found to be less than 15 feet thick.

The Genesee is excellently exposed above the Tully limestone at numerous outcrops along the Keuka Lake Outlet and on the west shore of Seneca Lake from Dresden southward. The Genesee dips steadily to the south except for several undulations and disappears beneath Seneca Lake on the north side of Smith Point, slightly northeast of the town of Starkey.

Genundewa limestone horizon.—The Genundewa limestone, so named from its favorable exposure at Genundewa Point, Canandaigua Lake, continues westward succeeding the black Genesee shale from this point as a thin-bedded limestone composed of the fossils of the minute pteropod *Styliolina fissurella.* At its type locality on Genundewa Point along Canandaigua Lake, it consists of three bands of limestone about 15 feet thick. It diminishes in thickness westward to Lake Erie, where it still maintains its lithologic character, but is only a few inches in thickness. From Canandaigua Lake it continues toward the southeast where it crops out in this area as a thin band of gray shale which contains nodules of fossiliferous siliceous matter and pyrite. Its stratigraphic position is definitely marked by large, flat, soft concretions occurring slightly beneath the horizon. These may be followed southward along the west shore of Seneca Lake from a point east of Himrod to Smith Point northeast of Starkey. Here it dips below the level of Seneca Lake and again rises above the water just south of the area and continues across Fir Tree Point in a small arch, definitely marking the position of the axis of the Fir Tree Point anticline.

West River shales.—The succeeding gray and black shales overlying the Genundewa limestone were originally termed the Upper Genesee shales, but subsequent investigations have designated them as the West River shales, due to their excellent exposure in West River Valley in western Yates County.

Lithologically, the shales consist of layers of dark gray shales separated at intervals by black shale and thin sandstones and flags. The

gray shales predominate, but the black shale increases in the upper part of the formation. Outstanding characteristics are the number of spherical or oblong concretions found singly or in rows and the persistence of the thin flags. The shales also become more arenaceous in the upper part. The sandstones become heavier and more numerous and the interval of the shale decreases in thickness. The West River shale is approximately 110-115 feet in thickness in the western part of the area and decreases in thickness toward the west, being 65 feet thick in the Genesee Valley and 11 feet on the shore of Lake Erie. East of the area the shales crop out on the eastern shore of Cayuga Lake, where the exposure is 35 feet in thickness. In the area under investigation the shales become more arenaceous on the southeast and east, marking a previously unnoticed change in deposition. The shales are 110-115 feet thick on the western border and approximately 125 feet on the eastern side of the area and decrease in thickness toward the south.

Favorable exposures of the shales may be found in Sartwell's Gully 1 mile south of Penn Yan; in Bruce's Gully along the Keuka Outlet; along the east side of Keuka Lake southward from Penn Yan to a point north of Crosby, and along the west shore of Seneca Lake, from Himrod southward to the southern terminal of the area, where it is exposed in an eastward facing escarpment along the shore of Seneca Lake.

Standish shales (including Crosby sandstone and Keuka flagstone). Crosby sandstone.—Overlying the West River shale is a heavy, massive brown sandstone, called the Crosby sandstone, and so named from its exposure at Crosby on the east shore of Lake Keuka and included as the basal member of the Standish shales in this area.

Lithologically the Crosby sandstone consists of two or more members of heavy brown sandstone, 6 feet or less in thickness, which in places weathers reddish brown on exposure. The upper members are the more massive and, due to their extreme hardness, short, step-like falls are formed by the sandstone, where it crops out in the stream bed of the ravine. The sandstone overlies a light gray shale 5 feet or more in thickness, which contains spherical or somewhat flattened concretions. At several outcrops these concretions extend into the base of the sandstone and are freely distributed throughout the light gray shale. Above the Crosby moderately thick sandstones and thin flagstones separated by gray shale occur for a short distance.

The Crosby sandstone is exposed along the east shore of Lake Keuka from Crosby to Penn Yan; in Sartwells Gully south of Penn Yan; eastward from Penn Yan on the south side of the Keuka Outlet for a dis-

tance of 2 miles, and along the west shore of Seneca Lake from Himrod southward to the southern border of the area, where changes in lithology of the sandstone cause difficulty in correlation.

Standish shales and flags.—The Standish shales and flags, which stratigraphically succeed the West River shale, consist primarily of heavy, bluish gray sandstones or flags and gray shales. Lithologically the Standish formation consists of two distinct divisions of sandstones and shales.

The lower division of the Standish is composed of heavy, massive, bluish gray sandstones and flagstones separated by layers of gray, sandy shale of varying thickness. Due to the extreme hardness of the sandstone members and softness of the interbedded shales, weathering produces short, step-like falls at all ravine exposures. Along the east side of Keuka Lake the lower division of the Standish is approximately 110-140 feet thick and increases toward the southeast, where the sandstones become heavier and more numerous along the west shore of Seneca Lake.

The upper division of the Standish is composed of a heavy bed of gray sandy shales in which occur several beds of black slaty shales. Spherical and somewhat flattened concretions occur sparingly throughout the shales, as do also thin sandstone layers. The soft shales weather in distinctive inclined beds of low gradient in the streams. The eroded gray shale fragments have a characteristic leaf-like appearance when exposed to weathering and the black shale intervals produce smooth, angular benches. Toward the upper terminal of the shales they become darker and make the transition between the Standish and Middlesex black shales very difficult to define, although at several exposures the transition from the gray to black shale is distinctly marked by a thin sandstone or an abrupt change from gray to black. The upper division of the shales varies in thickness from 100 to 135 feet and appears to lose its character and thickness toward the southeast, where the shales are gradually replaced by incoming heavy sandstones and thin shales.

The beds of the Standish shales, which succeed the West River shales in the Naples valley, were until the present investigation believed to be limited in occurrence to that area in the vicinity of Canandaigua Lake where the shales are approximately 15 feet thick. The present work discloses that the Standish formation increases in thickness and changes in character toward the east and southeast and becomes an important formation in the area under investigation.

The Standish shales and flags have an average thickness of 75 feet on the western border of the area, increase to 250 feet in the central part, and are 300 feet thick on the eastern terminal.

In the original investigation of the area the heavy sandstones and gray shales were correlated as Cashaqua shales. With this subsequent work they are disclosed to be the Standish shales and flags, a formation which closely resembles the Cashaqua formation, but differs in the reversed position of sandstones and shales.

Favorable exposures occur along the east and west shores of Keuka Lake; along both sides of the Keuka West Branch and in the extreme southeast corner of the area on the hills and in the stream ravines west of Seneca Lake.

Keuka flagstone.—The Keuka flagstone, so named from its excellent exposures on all shores of Keuka Lake, is a hard, dark gray flag, 2-4 inches thick, occurring 85-90 feet below the top of the Standish formation and approximately midway between the upper and lower divisions. It is easily recognized by its position between dense black shales or a thin layer of light gray shale intervening between the flag and the black stratum beneath it. The flagstone on weathering assumes a rough, wavy appearance on its upper surface and protrudes from above the underlying soft black or gray shales in a manner which is very distinctive.

The Keuka flagstone crops out along both shores of Keuka Lake and along the Branchport terminal of the Keuka West Branch. The only eastern exposure occurs in the bed of the creek in Plum Point Ravine west of the town of Himrod near the west shore of Seneca Lake.

Middlesex black shale.—Succeeding the Standish shales is a band of densely black shales designated the Middlesex from its favorable exposure in the Middlesex valley in Yates County. The shales are soft, homogeneous, and fissile. On exposure in the ravine they become discolored to distinct reddish brown.

The shales increase in thickness from west to east. In the Middlesex valley the stratum is 35 feet thick and diminishes to a thickness of 6 feet on Lake Erie. On the western border of the area investigated it is 40 feet thick, in the central part 55-60 feet thick, and in the east 80 feet thick.

The shales are exposed in nearly all ravines in the area, particularly as a fine vertical outcrop over the entire thickness in the Chilsey Point Ravine. The exceptions, where outcrops of the Middlesex are lacking, are the northern part of Milo Township and the southern part of Torrey Township. The Middlesex occurs as a part of the surface formation on the ridge of the divide between Seneca Lake and Keuka Lake and crops out in several good exposures, particularly east of Second Milo and in a ravine 2 miles northwest of Shannon Corners.

Cashaqua shale (including Parrish limestone).—This formation is composed of olive, sandy shales and thick sandstones interbedded with thin flagstones, which are found to be more numerous in the upper zone of the Cashaqua.

The lower part of the Cashaqua is composed principally of olive-colored shales in which a few thin sandstones are distributed. The transition from the black Middlesex shale to the olive-gray shale is very gradual, but the change is easily detected by the sandy characteristic of the black Middlesex shales and lighter color of the Cashaqua shales as the contact point between the two formations is approached. The lower portion of the Cashaqua is succeeded by a zone of massive sandstones and shales; its contiguity to the lower zone is marked in many ravines by very abrupt and extremely high falls. Toward the east numerous bands of black shale invade the lower zone of the Cashaqua and occur in many outcrops immediately below the section of heavy sandstone. The shales are 135 feet thick on the western border of the area and decrease in thickness and lose in character toward the south and southeast, being absorbed in part by the thickening of the Middlesex shales and the increasing deposition of arenaceous material.

The upper zone of the Cashaqua is composed entirely of heavy, massive sandstones and thin flagstones separated by bands of gray shale, and in a few places calcareous concretions are found within the shale beds. Near the top of the Cashaqua formation a thin nodular limestone, called the Parrish limestone, occurs interstratified in the sandstones and shales.

The Cashaqua formation thickens from west to east, being 32 feet thick in the cliffs along the shore of Lake Erie. It is 165 feet thick in the Genesee River gorge; 250 feet thick in the vicinity of Canandaigua Lake; 300 feet thick in the Chilsey Point Ravine in this area; and in Wagener Glen north of Pulteney is 314 feet in thickness. The Cashaqua increases in thickness toward the southeast in this area, but again decreases in thickness in a general southeast direction outside the border of the area and is found to be 205 feet thick at Watkins Glen at the southern limit of Seneca Lake.

The Cashaqua formation is favorably exposed on the hills along the east and west shores of Keuka Lake and its West Branch, in the northern part of Jerusalem Township, and the northeast section of Starkey Township.

Parrish limestone.—Outcropping in Parrish Gully near Naples in the Canandaigua Lake region is a hard, gray-brown, nodular limestone,

4 inches thick, characterized by its large nautilid fossils and in places crystalline appearance when broken, which has been used extensively as a key bed in structural mapping. It does not extend west of the Naples valley, but increases toward the east and south and attains its greatest development on the west shore of the Keuka Lake West Branch.

The limestone generally occurs interstratified in the Cashaqua sandstones and shales about 20 feet below the Cashaqua-Rhinestreet contact, but the interval decreases toward the south in this area. In the northern part the interval is 21 feet and decreases to 6 feet in a ravine near South Pulteney where the limestone is exposed.

The Parrish limestone locally increases in thickness toward the south, but nowhere attains a thickness of more than 2 feet. It crops out continuously in favorable ravines along the west side of the Keuka West Branch and is found on the west side of Bluff Point. Although evidence of its occurrence on the east side of the same bluff is found, no outcrops of the limestone are found. It occurs in several exposures along the east shore of Keuka Lake, but farther east does not appear as structural conditions project the limestone above the surface horizon.

Rhinestreet black shale.—The Rhinestreet formation is composed of densely black, slaty, bituminous shales with a distinct kerosene odor when freshly exposed. The contact of the black shales and the underlying gray Cashaqua formation is very distinct, although at several exposures thin sandstones invade the black Rhinestreet shales and are found interstratified in the basal part of the Rhinestreet formation separated by black shales.

The Rhinestreet formation increases in thickness toward the west and north. Along the shores of Lake Erie it is 185 feet thick and decreases in thickness toward the east. It is 40-50 feet thick in the Naples valley; 18 feet in the ravine at Guyanoga in this area; 15 feet thick in the Wagoner Ravine near Pulteney; and in the central part of the area it is 4 feet thick.

The Rhinestreet black shale is exposed favorably along the west shore of the Keuka Lake West Branch and northward; along the east side of the same branch in a few exposures; at several outcrops along the east shore of Keuka Lake; and in a ravine 1½ miles southeast of Warsaw in Barrington Township.

Hatch shales and flags.—The Hatch formation is composed of beds of soft, olive-gray shales separated at intervals by bluish gray sandstones and flagstones varying in thickness from a few inches to several feet. Streaks of black shale less than 4 feet in thickness are found interstrat-

ified at intervals in the formation. The sandstones and flags appear to be more numerous in the middle and upper parts, although both appear in many places in the lower section. The lower section of the Hatch somewhat resembles the Cashaqua formation, but appears to be poorly bedded. The sandstones vary in thickness from an inch to 2 feet and are generally very hard and dark. The beds become softer and lighter-colored toward the west and in many places contain concretions and pyrite in both shales and sandstones. The formation decreases in thickness toward the west and increases in thickness toward the southeast. It is 150 feet thick in the Genesee River gorge and approximately 300 feet thick in this area.

The Hatch formation is exposed in the ravine at Friend, slightly northwest of the area investigated, in Belknap Gully at Guyanoga, and in the upper part of Wagoner Gully near Pulteney.

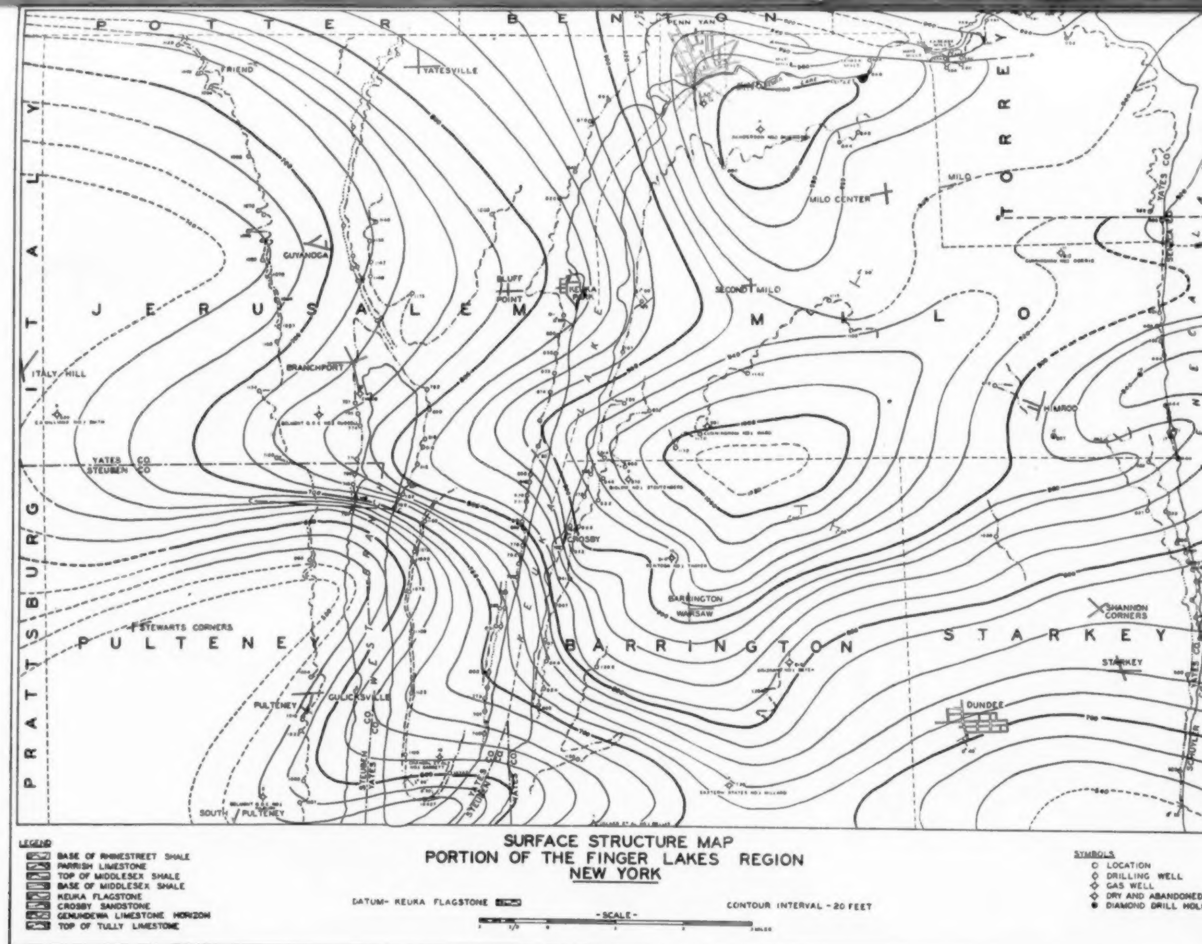
Grimes, West Hill, Highpoint, and Prattsburg formations.—These formations, consisting of sandstones or shales or both shales and sandstones, constituting the members of the upper Portage group and basal Chautauquan group, crop out so rarely that it is impossible to follow definite key horizons with any degree of accuracy. For this reason detailed description of the beds is omitted from this paper.

The only favorable exposures of these formations in this area are found west of the Keuka Lake West Branch in Wagoner Gully and westward from this point in the vicinity of Italy Hill.

STRUCTURE

In New York state the Appalachian system of folding consists of a series of folds which extend in a general northeast direction superimposed on the regional southwest dipping strata. In the vicinity of Seneca Lake the continuous northeast strike of the folding is deflected east and west. The Appalachian folds extend for considerable distances and where changes of direction of strike occur, indicating the point of intersection of the Ordovician system of folding and the later Paleozoic folding, considerable faulting of the strata occurs and domes of proportionate magnitude are formed.

The structural features of the area are determined from the exposed rocks and records from wells recently drilled. Figure 2 shows the structural contour map drawn on the Keuka flagstone, which is used as the datum key bed in the interpretation of structural features of the region. The contour interval is 20 feet and the figures give elevations above mean sea-level. The major structure (Barrington-Milo) is a closed dome of



SURFACE STRUCTURE MAP
PORTION OF THE FINGER LAKES REGION
NEW YORK
DATUM- KEUKA FLAGSTONE
CONTOUR INTERVAL - 20 FEET
- SCALE -
LEGEND
BASE OF RHINESTREET SHALE
PARRISH LIMESTONE
TOP OF MIDDLESEX SHALE
BASE OF MIDDLESEX SHALE
KEUKA FLAGSTONE
CROSBY SANDSTONE
GENUNDEWA LIMESTONE HORIZON
TOP OF TULLY LIMESTONE
SYMBOLS
LOCATION
DRILLING WELL
GAS WELL
DRY AND ABANDONED
DIAMOND DRILL HOLE
POTTER
BENTON
TORREY
ITALY
JERUSALEM
MILO
PRATTSBURG
PULTENEY
BARRINGTON
STARKEY
PENN YAN
YATESVILLE
FRIEND
GUYANOGA
BRANCHPORT
ITALY HILL
BLUFF POINT
MILO CENTER
SECOND MILO
HIMROD
CROSBY
BARRINGTON
WARSAW
STEWARTS CORNERS
PULTENEY
GULICKSVILLE
SOUTH PULTENEY
DUNDEE
SHANNON CORNERS
STARKEY
YATES CO
STEUBEN CO
SCHUYLER CO

FIG. 2

80 feet formed at the point of intersection of two different systems of folding, which cause a flexure in the normal Appalachian system of folding. The rate of dip varies from 120 feet per mile on the steeper flanks of the dome to 20 feet on other sides. A saddle separates the Barrington-Milo dome from a much smaller dome on the north which is faulted on its northern side.

FAULTING

Faulting is of considerable importance in the area investigated. Numerous faults occur, some of which are only local in importance and magnitude. Evidence of tremendous underthrusting forces which distorted and broke the formations, forcing the competent members into steeply dipping minor folds, or faults of limited displacement, is found in many ravines, especially in the regional synclines where lack of pressure relief causes considerable distortion and disturbance of the strata.

Keuka Outlet fault.—The most pronounced fault in the area is found along the Keuka Outlet between Seneca Mills and Cascade Mills, where the Tully limestone is found to crop out twice in the same stream bed with a displacement in excess of 60 feet in what appears to be a normal fault.

Chateau Duggas fault.—Probable evidence of a fault exists in a ravine 2 miles south of Branchport near Chateau Duggas, where the Middlesex black shales dip abruptly at an angle of 22° and show considerable bending before fracturing as a fault.

Pioneer Camp fault.—At Pioneer Camp, on the west side of Seneca Lake, a fault is indicated by the abrupt disappearance of the Tully limestone and the presence of the overlying Genesee shale beds in the succeeding ravine less than ¼ mile farther south. The fault has a displacement of more than 43 feet and appears to be of the normal type.

GAS RESERVOIR ROCK

Oriskany sandstone.—Considerable drilling has been done in the area in an effort to find commercial gas production in the Oriskany sandstone, but up to the present there has been little success. The Oriskany sandstone is found commercially productive in the Tyrone field, Schuyler County, directly south of the area, in the Farmington field, Tioga County, Pennsylvania, and in several test wells recently drilled in northern Pennsylvania.

The sandstone at its type locality, at Oriskany Falls, New York, is a uniformly bedded, coarse-grained, fossiliferous, cream-colored sandstone about 12 feet thick. The well rounded quartz sand grains are some-

what loosely cemented with calcite, although some siliceous cementing material is present. The sandstone is somewhat massive and contains numerous black concretions in the upper part. Eastward from its type locality the lithology of the sandstone changes appreciably. The proportion of calcareous matter increases so markedly that the Oriskany assumes the characteristics of a sandy limestone. Favorable outcrops of the sandstone are rare, but westward it is excellently exposed in Yawger's Wood, on the east shore of Lake Cayuga, several miles north of Union Springs. Here the sandstone consists of multiple members of heavy, irregularly bedded, coarse-grained sandstone. Fossils are very abundant and many specimens of brachiopods are found to be well formed. West of Seneca County the sandstone loses its characteristic form and is rarely found as the characteristic Oriskany. The character of the sandstone is extremely variable. At some localities, the columnar position can only be inferred by the appearance of a sandy limestone occurring between the overlying Onondaga limestone and the upper Silurian limestones. At others, the sandstone is extremely fine-grained, tightly cemented, and very hard.

The Oriskany sandstone deposited in a rapidly transgressing sea on the west represents the most irregular and least continuous of the Devonian formations. The rapidity with which the westward movement of the sea was maintained prevented a uniform deposition of sand from the eastern land mass. The presence of Oriskany sandstone represents old shore lines, showing that the westward encroachment of the seas was retarded, or marine bar deposits protected from erosional water action of swift sea currents.

Although the Oriskany sandstone conforms closely to surface expression of closed anticlinals, because of the variability of its occurrence, studies of the depositional features, character of the sand, and lateral extent of the sand are necessary for successful exploitation of gas-producing fields.

Depths to the Oriskany sandstone encountered in wells already drilled in this area are given in Table I.

CONCLUSION

The Portage group of the Devonian system in the Keuka-Seneca Lake area is of more importance than previously credited. Its formations, including especially the Middlesex shale and Standish shale, are given greater regional extent. The Standish is now known to be a formation not only of local importance in the Naples area, but of regional

TABLE I

Map No.	*Well*	*Operating Company*	*Depth to Oriskany Sand (in Feet)*	*Thickness of Sand (Feet)*	*Well Status*
1	Russell 1	B. Q. D. C.*	1,492		Salt water
1	Russell 1	B. Q. D. C.	3,310**		Dry
2	Kilbury 1	B. Q. D. C.	1,932		Dry
3	Beyea 1	Oriskany Dr. Co.	1,940		Dry
4	Sanderson 1	Sanderson		5	Dry
5	Millard	E. S. N. G. Co.†	1,967	11	Dry
6	Smith 1	E. A. Williams	1,899	13	Salt water
7	Bellie 1	Decker *et al.*			Salt water
8	Ward 1	C. O. G. Co.‖	1,999	5	Dry
9	Stoutenberg 1	Biglow Gas Co.		22	Dry

*Belmont Quadrangle Drilling Company.
†Eastern States Natural Gas Company.
‖Cunningham Oil and Gas Company.
**Medina Sandstone

importance in regard to extent and lithology, its character and thickness changing in an eastward and southeastward direction.

Deep underthrusting forces finding relief and expression in the Barrington-Milo dome elevate the lower Portage beds to such an extent that the previously correlated Cashaqua formation along Seneca Lake is now known to be the Standish formation.

Although structural conditions of the Barrington-Milo dome favor accumulation of gas, and source beds furnish an abundance of carbonaceous and bituminous material, the depositional features and lateral extent of the Oriskany sandstone are required to be of equal importance to favor productiveness of the sand.

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REGIONAL STRUCTURE OF CRETACEOUS ON EDWARDS PLATEAU OF SOUTHWEST TEXAS[1]

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ABSTRACT

The surface rocks of the Edwards Plateau are of Lower Cretaceous age, and comprise the Trinity, Fredericksburg, and Washita divisions.

The Trinity division was deposited by a sea encroaching upon an upland plain, traversed by several broad south- and east-draining river valleys, and broken by ridges formed on outcropping resistant formations. Trinity deposits filled the lower areas of the floor of deposition, so that the succeeding Fredericksburg deposits were laid upon an almost level surface except for the tops of some ridges which were never submerged in Trinity time.

The regional structure, as contoured on the base of the Fredericksburg, shows a central plateau high zone with gentle coastward dip comprising most of the Edwards Plateau proper, and a peripheral belt of steepened dip on the south and east. Comparison of regional contour maps of the pre-Cretaceous surface, Trinity thickness, and the base of the Fredericksburg, shows clearly that the regional structure of the Fredericksburg is controlled by the topography of the pre-Cretaceous surface, and down-warping of the south and east margins into the Balcones fault zone.

INTRODUCTION

The Edwards Plateau is an extensive upland region in southwest Texas, about 150 miles long from east to west, and 125 miles wide from north to south. It lies essentially between the cities of San Angelo, Del Rio, San Antonio, and Austin, and embraces all or parts of twenty-five counties. Geologically, it is located southeast of the Permian basin province, southwest of the Bend arch province, and north and west of the Balcones fault. The Central Mineral region is an unroofed, broad, low dome in its northeast corner.

The Edwards Plateau consists of a small, flat, central plain in southern Schleicher, Sutton, and northern Edwards counties, which gives way to a progressively more dissected terrane as the margins of the plateau are approached. Its surface is upheld by the massive Edwards limestone, and younger limestones, and though smooth and level locally, is generally rolling and benched. It supports a low timber growth of cedar and scrub

[1]Read by title before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, March 13, 1932.

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oak, which is very dense in some parts. Where marginal streams cut back into it, there are deep canyons with valley floors lined with large trees. The surface is used almost exclusively for ranching.

The surface formations of the Edwards Plateau are relatively flat-lying Comanche rocks, except for a few small inliers of Permian and Pennsylvanian. The contact of the Fredericksburg and Trinity divisions of the Comanche group is the only distinctive horizon readily traced throughout the whole region, and this is not everywhere present or exposed.

The contour maps which accompany this paper are based on reconnaissance field work by the writer, and well-log interpretation. For the areas east and south of the Central Mineral region, control data are taken from geologic literature, publications by R. T. Hill, Hill and Vaughan, Sidney Paige, and Alexander Deussen.[1]

The maps are essentially preliminary regional interpretations. In several places local details are generalized because of undeveloped economic possibilities. Much of the work upon which this paper is based was done by the writer for the Superior Oil Company of California. Their permission to publish was generously given.

STRATIGRAPHY

The stratigraphy of the Cretaceous on the Edwards Plateau is relatively simple. Only Lower Cretaceous or Comanche beds are now represented. They are divided into three divisions, namely, Trinity, Fredericksburg, and Washita. In general, the rocks of the Trinity division were laid down upon a subsiding bottom of the former land surface; rocks of the Fredericksburg division upon a stationary off-shore bottom; and rocks of the Washita division upon a shallowing bottom of Fredericksburg sediments. There appear to be no marked unconformities between these divisions.

The Trinity division consists of a basal unit called the Basement sands, and an upper unit called the Glen Rose formation. The Basement sands consist of fine and coarse sands and much pale gray and maroon clay. The lowest beds are commonly conglomeratic. The lithology of the Basement sands varies with the lithology of the floor on which

[1] R. T. Hill, "Geology of the Black and Grand Prairies," *U. S. Geol. Survey 21st Ann. Rept., Pt. 7* (1901).

R. T. Hill and Wayland Vaughan, "Geology of the Edwards Plateau and Rio Grande Plain Adjacent to Austin and San Antonio, Texas," *U. S. Geol. Survey 18th Ann. Rept., Pt. 2* (1898).

Sidney Paige, "Llano-Burnet Folio," *U. S. Geol. Survey* (1912).

Alexander Deussen, "Geology of the Coastal Plain of Texas West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924).

they rest, and on the Edwards Plateau the formation usually contains more clay than sand. It is not a true formation in the common sense, because, while it is the local bottom of the Comanche beneath any particular area, it is not everywhere of the same age. The sands grade south and east, seaward, into deposits of quieter waters. Hill[1] says,

> . . . the Basement sands of the Trinity division and of the Comanche series in general, represent the coalesced interior margin of many seaward formations, and may be treated as a continuous formation which traversed the column diagonally as the Comanche sea invaded a subsiding land. . . .

The Basement sands usually are less than 250 feet thick in the northern part of the plateau, and are absent altogether in areas topographically high on the old land surface. Where they are absent, beds of the Fredericksburg division, in many places not the basal Fredericksburg, rest directly on the older rocks. In the southern part of the plateau, the Basement sands thicken to as much as 450 feet.

The Glen Rose formation is a seaward phase of the Trinity, and consists of flaggy, argillaceous, and massive chalky limestones, alternating with gray clays and yellow marls. It is found only in the southern part of the Edwards Plateau, where the underlying floor of Paleozoic rocks slopes more sharply toward the south. Its northward termination merges into the Basement sands. A thickness of 1,240 feet is known in northern Uvalde County, and 60 miles south, in central Maverick County, there is a thickness in excess of 3,600 feet, according to Vanderpool.[2]

The Fredericksburg division overlies the Trinity division. The lower 15 feet of the Fredericksburg comprises the Walnut clay, a yellow marly clay carrying abundant *Exogyra texana* and constituting a valuable marker for regional mapping. The Walnut is overlain by the thin chalky Comanche Peak limestone and the thick resistant Edwards limestone. The Fredericksburg division thins from 675 feet in southern Edwards County to 204 feet in Irion County. In Irion County it shows more of the marly aspect characteristic of North Texas.

Beds of the Washita division overlie the Fredericksburg in some parts of the plateau, although erosion has stripped the surface down to the Edwards limestone over the greater extent of it. The Washita division comprises the Georgetown, Del Rio, and Buda formations, and consists of limestones, marls, and clays which carry a distinctive fauna.

[1]R. T. Hill, *op. cit.*, p. 133.

[2]H. C. Vanderpool, "Cretaceous Section of Maverick County," *Jour. Paleont.*, Vol. 4, No. 3 (1930), p. 253.

TOPOGRAPHY OF PRE-CRTACEOUS SURFACE

There was marine deposition in most of this region during the Pennsylvanian and Permian periods, but during the Triassic and Jurassic periods the region was above sea-level and extensively eroded. At the beginning of the Cretaceous period, the Edwards Plateau was a rolling upland plain or plateau, cut by several broad river valleys, and marked by ridges along the outcrop of the harder formations. At its south and east margins it descended, by comparatively steep slopes, to the level of a coastal plain. This old surface elsewhere in Texas has been referred to by Hill[1] as the Washita paleoplain.

The present relief of this pre-Cretaceous surface, or floor of deposition, is illustrated by Figure 1. These contours depict the sum of the original topographic slopes plus later structural warpings of this surface.

The Trinity division was the basal deposit of the Cretaceous laid down by an advancing sea, and filled the inequalities of the surface so that the floor of the sea in the subsequent Fredericksburg epoch was essentially flat except for certain island masses never covered by the Trinity sea. Figure 2, an isopach map of the Trinity division, shows the areas of thickest Trinity deposits, which were necessarily topographically lowest on the old floor of deposition, the pre-Cretaceous surface, and the areas of thinnest Trinity deposits and of no Trinity deposits, which were necessarily highest. The thickness of Trinity on this map ranges from almost nothing to 1,700 feet. This means that during Trinity time, through a combination of differences in original topography and contemporaneous warping of the floor of deposition, there was as much as 1,700 feet of topographic relief, and hence of material deposited at one place which was never deposited at another. The part of the floor most depressed by warping is that now covered by the Glen Rose formation.

The Fredericksburg was laid down on a comparatively level floor of Trinity, excepting where the Trinity was absent, at which places the Fredericksburg was deposited on the uneven pre-Cretaceous surface. Thus, at the time the Fredericksburg was being laid down on a level sea-bottom, floored with Trinity, the pre-Cretaceous surface deeper down was inclined, and the Trinity beds between the pre-Cretaceous floor and the Fredericksburg formed a wedge which built this inclined surface up to a level plane. So the rate of change of thickness of the Trinity between two points is a measure of the rate of slope the pre-Cretaceous floor had in basal Fredericksburg time.

[1] R. T. Hill, *op. cit.*, p. 129.

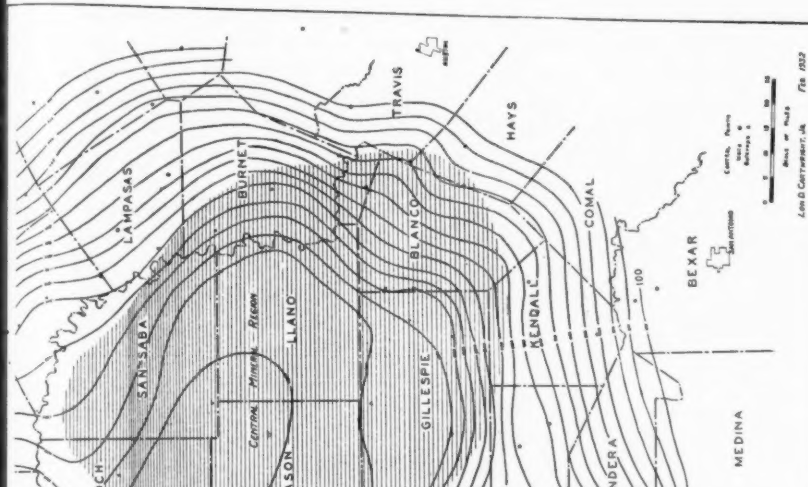

FIG. 1.—Contour map of pre-Cretaceous surface on Edwards Plateau. Outcropping resistant formations on this surface are indicated by shading. Outcropping easily eroded formations are blank. Contour interval, 100 feet.

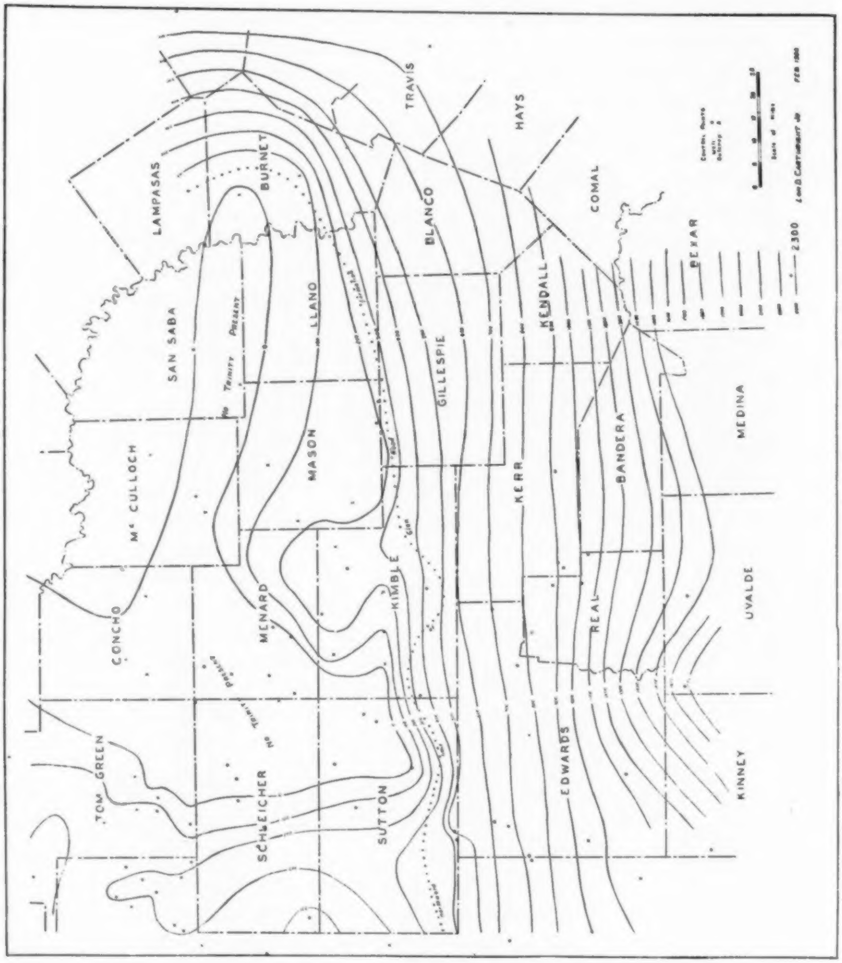

FIG. 2.—Isopach map of Trinity division on Edwards Plateau.

Contours on the base of the Fredericksburg (Fig. 3) represent differential movement after basal Fredericksburg time. The contours on the pre-Cretaceous surface represent the present attitude of the pre-Cretaceous surface, and the isopach lines on the Trinity represent the attitude of the pre-Cretaceous surface in basal Fredericksburg time. The difference between the rates of slope indicated by contours of Figure 1 and the rates of slope indicated by contours of Figure 2 should equal the rates of slope indicated by contours of Figure 3. This condition is approximately met, and where it is not met the lack can be ascribed to the incomplete data on which the maps are drawn. A quantitative comparison of these contoured surfaces indicates that five-eighths to three-fourths of the contoured relief of the pre-Cretaceous surface is original topography and pre-Fredericksburg warping, the remaining one-fourth to three-eighths being post-Fredericksburg warping of its east and south peripheral belts.

An examination of the pre-Cretaceous topography reveals a high area at the Central Mineral region, flanked by a pre-Cretaceous south-draining valley on the west and a pre-Cretaceous east-draining valley on the north. It shows a high area on this old surface in eastern Schleicher County extending down into Sutton County, flanked by pre-Cretaceous south-draining valleys on the east and west. East of the Central Mineral region is a more steeply sloping peripheral belt which swings around it on the south and continues westward through Bandera, Real, Edwards, and Valverde counties.

The rocks beneath the Cretaceous in the Central Mineral region are granite, massive limestone, and other hard materials. Beneath the Cretaceous in the eastern Schleicher County topographically high area is a massive Permian limestone of Wichita-Clear Fork age, the outcrop of which on the pre-Cretaceous surface forms the topographically high area. The rocks beneath the Cretaceous in the valleys flanking the high areas and on the marginal slopes are principally shales and sandstones, less resistant materials. Hence, the pre-Cretaceous topography is demonstrably controlled by the areal distribution of hard and soft formations on the old floor of deposition.

REGIONAL STRUCTURE

The contour map of the base of the Fredericksburg division (Fig. 3) is essentially a map of the regional structure of the Cretaceous on the Edwards Plateau, because it depicts the attitude of a single horizon or time plane throughout the region. It shows the beds to be almost flat

FIG. 2.—Isopach map of Trinity division on Edwards Plateau.

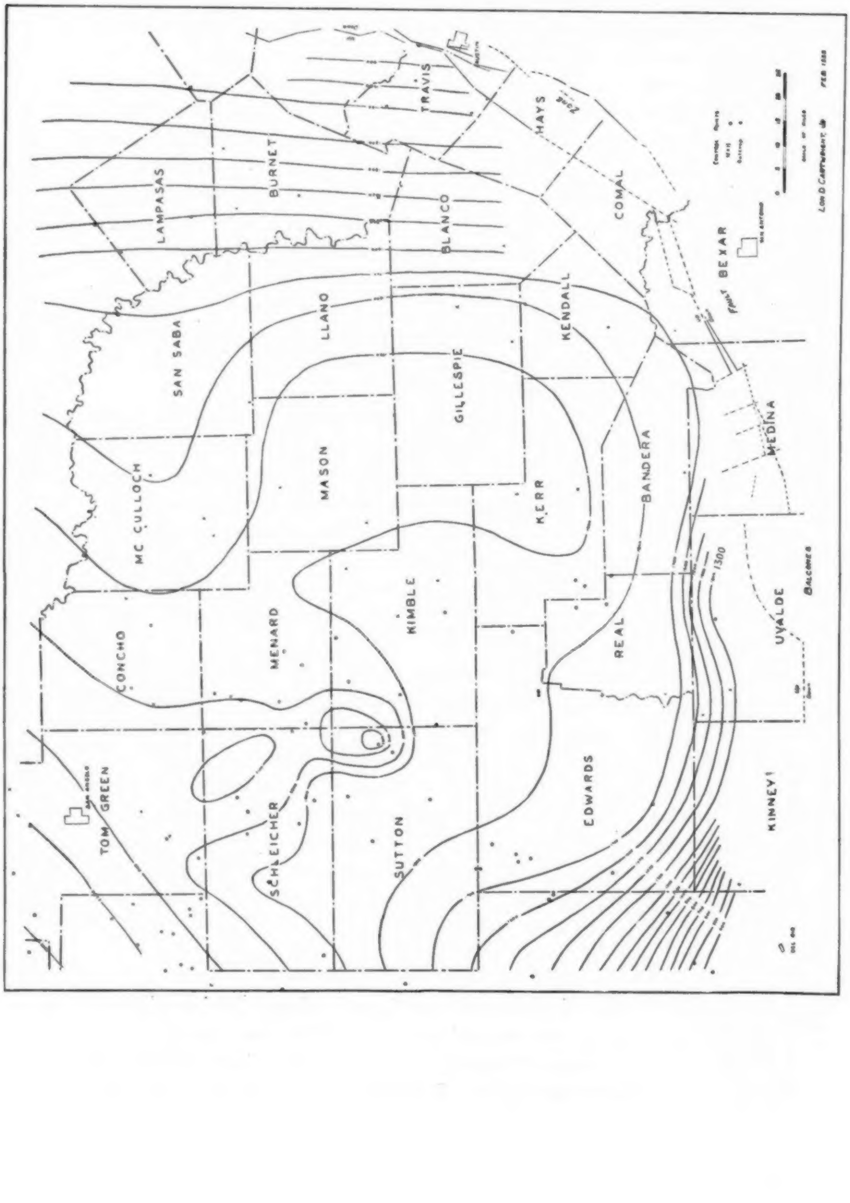

FIG. 3.—Regional structure of Fredericksburg division on Edwards Plateau. Contours on base of Fredericksburg. Contour interval, 100 feet.

in a regional sense, over all but the south and east margins of the plateau, where they dip more steeply into the Balcones fault. In limited areas of the plateau, there are local domes and anticlines having closures of as much as 100 feet in some instances. These are not shown in Figure 3, which was drawn to show a rational picture of the regional structure, without regard for local deflections. The outstanding features of regional structure are: (1) a central-plateau high zone covering most of the Edwards Plateau proper, and including Schleicher, Menard, Sutton, Kimble, Edwards, Kerr, Real, Bandera, Kendall, Gillespie, Mason, and Llano counties; and (2) a peripheral belt of steepened dip on the east and south margins of the plateau, extending down to the Balcones Fault, and passing through Valverde, Kinney, Uvalde, and Medina counties on the south, and Blanco, Burnet, Lampasas, Travis, and Williamson counties on the east. Taken together, these features constitute a broad, southeast-pitching regional fold, the axis of which extends from Tom Green County to Kendall County. This fold might well be called the Comanche platform of the Edwards platform.[1]

The central-plateau high zone comprises most of the region of the plateau. It consists of an elongate north-south dome in eastern Schleicher County, divided by a saddle and extending south into Sutton County, flanked by broad, gentle synclines; and a broad, north-south elongate dome in the Central Mineral region, bounded on the west and north by broad, gentle synclines, and on the east by a monoclinal dip. South and southwest of these two domes is a broad, flat terrace bounded on the south by a flexure which steepens the dip into the Balcones Fault zone. Much of this terrace is developed on a supporting wedge of Glen Rose, under which the Paleozoic floor slopes southward more rapidly than the dip of the Fredericksburg.

A comparison of the structure map of the base of the Fredericksburg, the topographic map of the pre-Cretaceous surface, and the thickness map of the Trinity division, reveals remarkable similarity of the larger features, and shows clearly that the regional structure of the Fredericksburg is controlled by the topography of the terrane upon which it was laid. The structural control exerted by this topography was probably twofold. First, the bottom of the Fredericksburg sea was not entirely flat,

[1]The term "platform" is used in preference to "arch" or "anticline" for two reasons. First, the shape of the structure, with its broad, almost flat top, its short steepened flanks, and large angle between the flanks, is well described by the term "platform." Second, the origin of the structure is considered to be from a depression of its flanks rather than from direct uplift or lateral compression; and the terms "arch" and "anticline" suggest these latter modes of origin.

FIG. 3.—Regional structure of Fredericksburg division on Edwards Plateau. Contours on base of Fredericksburg. Contour interval, 100 feet.

as is shown by the absence of Trinity in certain areas. The plastic lime muds and marly clays, as they were deposited, probably adapted themselves to the slopes, assuming gentle dips conformable in direction, though not in degree, to the slope of the surface on which they were deposited. Second, the soft clays of the Basement sand member were thickest in the former valleys and on the lower slopes. As the hundreds of feet of overburden accumulated, the clays suffered compaction, and the overlying beds settled. Laboratory experiments in the compaction of clays show volume reductions ranging from 43 to 52 per cent[2] without lithification of the clays. The areas of thickest clay deposition correspond with the areas of lowest topography on the pre-Cretaceous surface, which thus localize the area of lowest structure in the Fredericksburg.

The southwest dip in the Fredericksburg in Edwards and Valverde counties is almost as steep as the slope of the old surface, and the Trinity does not thicken very rapidly on this slope. This indicates a post-Fredericksburg flexing of the beds, which extends eastward through northern Kinney, Uvalde, and Medina counties, and is considered to be a part of the Balcones fault adjustment.

CONCLUSIONS

The conclusion is reached that the regional structure of the Cretaceous on the Edwards Plateau is controlled by the topography of the old Paleozoic floor upon which the Cretaceous was deposited, and by the comparatively late down-warping of the east and south margins at the time of the Balcones adjustment.

Nothing is said here about the origin of local domes or anticlines in the Cretaceous beds and their possible relation to older uplifts of the underlying formations, or to local post-Cretaceous uplifts affecting alike the Cretaceous and underlying beds. Local structures may be interpreted intelligently in the light of regional geology, and criteria set up by which their significance may be appraised.

[2] C. E. Nevin and R. E. Sherrill, "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), p. 17.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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GEOLOGICAL NOTES

HIGH ISLAND DOME, GALVESTON COUNTY, TEXAS

With reference to a salt dome that was unsuccessfully developed from a commercial standpoint through the operations of several oil companies during a period of a score of years, it is interesting to note that the High Island dome, Galveston County, Texas, is at present regarded as one of the promising oil fields of the Gulf Coast. The Yount-Lee Oil Company's development of the Cade lease, located northwest of the topographic "high," with a record of four flowing producers out of five wells drilled during the past 9 months, and the present drilling of three wells, undoubtedly created such interest as to justify the publication of these notes.

The oil showings and productive horizons in the new proved area are found in the Miocene formation, approximately from 100 to 1,200 feet below the Pliocene-cap rock-salt-Miocene contact, that is, in accordance with the present known overhang of the cap rock and salt. The Pliocene formation lies above the cap rock, and the true Miocene formation is found underneath the cap rock, or salt, whichever the case may be, as only the cap rock was found in the wells not encountering salt. The Yount-Lee Oil Company's Cade No. 28, located 740 feet W. of E. line, 1,370 feet S. of N. line of Cade Subdivision, N. Fitzsimmons Survey; Cade No. 24, located 1,010 feet from NE. line and 1,250 feet from NW. line of N. Fitzsimmons Survey, or 300 feet W. of Cade No. 22; and Cade No. 25, located 100 feet W. of Cade No. 23, were drilled exceedingly near the flanks of the salt, and the drill passed through the cap rock, but the salt was absent underneath. The Yount-Lee Oil Company's Cade No. 21, located 620 feet W. of E. line, 1,080 feet S. of N. line of Cade Subdivision, N. Fitzsimmons Survey, penetrated the cap rock at 4,592 feet, struck salt at 4,777 feet, and passed through the overhang and into true Miocene formation at 4,821 feet. The Yount-Lee Oil Company's Cade No. 23, located 300 feet S. of Cade No. 22, also encountered salt from 4,631 to 4,741 feet, and the last core taken, at the depth of 4,741 feet, before drilling trouble caused the abandonment of the well, showed that it contained a little salt, sand rock and limestone, and considerable shale: an indication that the drill was at the very point of passing through the salt. The productive sands in the wells mentioned,

as cored, show a thickness ranging from 60 to 120 feet, due, of course, to the steep dips that these sands have as they lie against the salt and cap rock.

The cap rock of the dome is divided into what might be called a series of caps. At the base of the series, or directly above the salt, the cap is uniformly massive anhydrite. The anhydrite passes upward into massive anhydrite and gypsum characterized by an abundance of calcite as a secondary mineral invading the gypsum. Whether or not there is a separate calcite cap above the anhydrite-gypsum is yet to be determined, although small masses of calcite have been cored. These materials constitute the *true* cap rock of the dome and are referred to as the *anhydrite-gypsum* cap rock. Above the true cap rock, there is a hard sand and lime rock (calcareous sandstone), ranging from 200 to 1,200 feet thick, which has been commonly termed the *false* cap rock of the dome. It is very difficult to drill through this false cap rock, as the material is exceptionally hard and well cemented. It was this material which caused the abandonment of wells drilled in the past years, as it was mistaken for the true cap rock of the dome.

The respective maximum thicknesses of the formations as determined from the wells drilled at High Island are as follows: Recent and Pleistocene formations approximately 1,200 feet, Pliocene formation approximately 3,600 feet, and the Miocene formation has been penetrated 1,200 feet. The Oligocene formation has not been encountered by any well drilled in the field to date.

The field at present is yielding 2,400 barrels of 27°-31° Bé. gravity oil per day.

M. T. Halbouty

Yount-Lee Oil Company
Beaumont, Texas
March 31, 1932

FOX HILLS FORMATION, NORTHEASTERN COLORADO

After a field conference with J. B. Reeside, Jr., of the United States Geological Survey, the Rocky Mountain Association of Petroleum Geologists has agreed to restrict the term "Fox Hills formation" as follows.

The base of the Fox Hills formation shall be considered as the horizon below which the section is predominantly gray marine clay shales and sandy shales of Pierre age, and above which the section changes rapidly to a buff to brown sandstone containing numerous large gray to brown, hard, sandy concretions. This lower concretionary member is commonly overlain by a series of light gray to brown sandstones and sandy shales.

The top of the Fox Hills formation shall be considered as the horizon above which the section is composed predominantly of fresh- and brackish-water deposits accompanied by coals and lignitic shales, and below which it is predominantly marine.

In the northeastern part of Colorado the Laramie formation, which immediately overlies the Fox Hills formation, is chiefly light gray clay shales and white sandstones containing numerous thin *Ostrea* and *Corbicula* beds and lignitic seams.

Localities where the Fox Hills formation is well exposed are as follows.

1. Jackson Lake, T. 5 N., R. 60 W., to Cottonwood Springs, T. 6 N., R. 60 W. The base of the Fox Hills is approximately 100 feet below the prominent bench 2 miles north of Jackson Lake, in Sec. 3, T. 5 N., R. 60 W.; the top is a white sandstone lying just below the lignitic shale in the canyon of the east branch of Cottonwood Springs Creek, on the south side of Sec. 12, T. 6 N., R. 60 W., and is approximately 65 feet below the general level of the surrounding plain.

2. One-half mile due east of Osgood, two thin *Ostrea* beds 5 feet apart mark the top of the Fox Hills formation in this region, although this horizon is stratigraphically lower than the top of the Fox Hills near Cottonwood Springs.

3. Near Poison Springs, Adams County, in Sec. 18, T. 3 S., R. 58 W., there is a good section of the Fox Hills formation 2-3 miles north of the Airline Highway. Its top is the white sandstone that underlies a lignitic shale which is well exposed near the southwest corner of Section 19, and its base is a yellow sandy concretionary zone, approximately 250 feet below the top of the white sandstone, and is well exposed in the SE. 1/4 of Sec. 17, T. 3 S., R. 58 W.

4. The contact of the Fox Hills and Laramie is exposed on Wildcat Mound in Sec. 27, T. 4 N., R. 67 W., about 50 feet below the Tertiary conglomerate that caps the hill; at this locality the top is marked by a prominent bench that can be easily followed several miles northeast and southwest. The base of the Fox Hills formation in this region is exposed in Sec. 3, T. 5 N., R. 67 W., southeast of Windsor, where a brown sandy concretionary zone overlies a gray marine shale. This horizon is approximately 250 feet below the base of the Laramie.

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
By its committee: T. S. LOVERING C. S. LAVINGTON
H. A. AURAND J. H. WILSON

DENVER, COLORADO
June, 1932

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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DISCUSSION

COMMENT ON *PETROLEUM OF THE UNITED STATES AND POSSESSIONS*

The easiest job in the world is to tear a fine work of art to pieces and to show up alleged crudities. That is not the purpose of these comments, which are prompted by an unfinished study of Arnold and Kemnitzer's *Petroleum of the United States and Possessions*.[1] As has been pointed out by Sidney Powers,[2] Dollie Radler,[3] and many other reviewers, this comprehensive volume is "monumental," and an "encyclopedia" of the oil industry. Not only the authors, but all who assisted with any advice, and those referred to in the most complete bibliography ever published may share in the pride of achievement.

While the presentation of statistics, tabulated facts, and production data, is recognized as invaluable by students of trade history, economics, and oil-field technology, this reader (not in the least iconoclastically) wishes to call attention to some points that appear too casually treated. There are several of these which the majority will no doubt consider positively non-essential, but only two are selected. From the commercial, present-day viewpoint they are indeed not important, but it is submitted that psychologically and historically they deserve recognition. Whence do we come, and why; and whither are we going? These are fundamental questions that should not lightly be passed over in any treatise on oil.

First is quoted the fifth paragraph, page 25.

> Exploratory wells—wildcat wells, or "wildcats," a word meaning not sound or safe, unreliable or irresponsible. It was early applied to exploratory wells, due to the hazard, not only of finding oil, but also to the shady character of the promotions and business schemes usually connected with such wells.

No doubt the layman will accept this, but I like better a definition by Hollis P. Porter.[4]

> *Wildcat*. A well in unproven territory, it makes no difference if prospects are good or bad. This is analogous to "prospect" in mining. An individual or corporation devoted to exploration far from where oil is actually known to exist.
>
> *Wildcatter*. One who drills wells in the hope of finding oil in territory not known to be an oil field.

[1]Harper and Brothers (New York and London, 1931).

[2]Sidney Powers, "Review of Petroleum in the United States and Possessions," by Ralph Arnold and William J. Kemnitzer, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932), pp. 103-4.

[3]Dollie Radler, Review in *Jour. Geol.*, Vol. 40, No. 2 (February-March, 1932), p. 188.

[4]Hollis P. Porter, *Petroleum Dictionary* (Gulf Publishing Company, Houston, Texas), p. 232.

About the earliest oil story ever told this writer was that the term "wildcat" was first applied to a (or any) courageous crew of real men that went out of civilization, far into the wilderness, "out among the wildcats," enduring hardships that they might drill a well, find oil, and make good. Out of the thousands of wildcatters there have been the unscrupulous and the charlatans; but after all are we not all, in one sense or another (good or bad), wildcatters? The oil industry and petroleum geology owe gratitude to that virile class. The oil man does not generally regard the term as one of opprobrium.

The foregoing relates to the psychological: as to the historical, see under heading "Drilling," page 26, as follows.

> Until 1905 practically all wells in the United States were drilled with cable tools, but at that time rotary equipment was first used successfully in the Gulf Coast field. Subsequently the use of rotary tools spread to all localities where the rocks were loosely consolidated, notably in California, but not until 1914.

These sentences are at least ambiguous, but further likely to create an erroneous impression of the evolution of drilling practice through the first decade of the Twentieth Century.

If "practically all wells" is confined to such as were drilled for oil, there is still confusion; but if "all wells" includes also drilling practice in search for water, see *Engineering News* (August 11, 1892). There is described a complete rotary rig and equipment with a 98-foot derrick, used in drilling for artesian water at Galveston, Texas. The well was drilled between April, 1891, and August, 1892, finishing with a 5-inch hole at 3,070 feet.[1]

The rotary method, then, efficient (as the cable tools were not) in soft formations, was in use in the Gulf Coast in the early nineties. In 1897, and before that, there were rotary drilled oil wells at Corsicana. After Captain Lucas' rotary-drilled success at Spindletop, Texas, in January, 1901, rotary drillers wildcatted all through the Gulf Coast fields to the practical exclusion of cable tools. Sour Lake and Jennings, 1902; Batson, Saratoga, and Welsh, 1903; and Humble, 1904, were some of the rotary major fields prior to the date 1905 as given.

The authors might speak with special authority on the occasional scattered locations of rotary drilled holes in California before 1914. However, it is here recalled that in 1908 at least one manufacturers' representative was in California trying to sell rotary equipment. Comparing the formational conditions with those in the Gulf Coast, he was strongly urging its more general California adoption in fighting the loose unconsolidated sands. He encountered strong opposition from established cable-tool drillers. Later came wide use of the rotary and many of the improvements of to-day's apparatus.

Historical inaccuracies similar to those here mentioned appear in other less meritorious publications on well-drilling methods, and have been reiterated in public addresses. It is suggested that accuracy as to dates is not positively necessary, but for the newcomer in the oil-production business, who can not properly read between the lines, elaboration of the facts may lead to increased respectful appreciation of our evolution up to the heights of the year 1932.

H. B. Goodrich

Tulsa, Oklahoma
June 9, 1932

[1]See also Robert T. Hill, *Amer. Jour. Sci.* (November, 1892); and E. T. Dumble and G. D. Harris, *Amer. Jour. Sci.*, 3d ser., Vol. 46 (1893), pp. 38-42, for complete logs and sampling by J. A. Singley. Also refer to *Texas Geol. Survey 4th Ann. Rept.*

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REVIEWS AND NEW PUBLICATIONS

Year Book, 1932, National Oil Scouts Association of America (Inc.). 273 pages, 12 maps, and many statistical tables, published by the Association, May, 1932. Price, $5.00, through J. W. Selby, Shell Petroleum Corporation, Dallas, Texas.

This *Year Book* is a compendium of the oil, gas, sulphur, and potash operations and development of the South and Southwest. The scouts of each of the nine districts: East Texas, Southwest Texas, West Texas, Southeastern New Mexico, West-Central Texas, North-Central Texas, Texas and Louisiana Gulf Coast, North Louisiana and Arkansas, Mississippi, have coöperated in compiling a most excellent summary of the oil development and operations in their respect've districts. Each district report comprises a brief review of the occurrence of oil and gas in the district, a brief comment on the history, development and present status of the oil and gas fields, a review of geological, geophysical, leasing, and drilling activity during 1931, production statistics, drilling statistics, data on pipelines and refineries, crude oil stocks. The report on the East Texas oil field is particularly detailed and includes: the Sunday shutdown experiment, gas wastage, list of wells making basic sediment and water on March 5, 1932, list of dead and pumping wells in Joiner area, field production statistics by companies, leases and districts (date of first production, past production to January 1, 1932, total number of producing acres, average production per acre, acres per well), pipeline outlets, capacity of refineries, total oil movement from the field for the year 1931, steel storage report for February 20, 1932. The report for the rest of the East Texas district comprises: fault-line and other fields of central East Texas; the Van field, Falls County, small shallow well; comments on wildcatting in East Texas by counties. The reports for the other eight districts are similar but are not as detailed as that on the East Texas oil field.

The *Year Book* is a notable contribution to oil literature. High credit is due to the National Oil Scouts Association of America, L. S. McGee and C. A. Strahan, who were in general charge of the compilation and editing of the volume, and their numerous district coöperators, for having turned out a most excellent job. The *Year Book* should be in the library of every economist or statistician whose field of interest includes oil production, every institution which teaches petroleum geology or petroleum engineering, all major oil companies, all lesser oil companies in Texas, Louisiana, Mississippi, Arkansas, New Mexico, and division offices in those states which maintain a library of more than half a dozen books, every oil geologist who maintains a library of more than half a dozen volumes on oil, all public libraries in those states, or at any oil center, independent oil operators and oil men in those states.

DONALD C. BARTON

HOUSTON, TEXAS
June 16, 1932

EL PETROLEO EN MEXICO

CORRECTION

In the June *Bulletin*, page 617, in John M. Muir's review of *El Petroleo en Mexico*, a line was accidently omitted. The sentence beginning on the seventh line of the second paragraph should read, "Sir Weetman Pearson (Lord Cowdray) is referred to as the second discoverer of oil in Mexico. From the bringing-in of the first successful well in Mexico on April 3, 1904, at Ebano; et cetera."

RECENT PUBLICATIONS

AUSTRALIA

"The Tertiary Geology of East Gippsland, Victoria, as Shown in Borings and Quarry Sections," by Frederick Chapman and Irene Crespin. *Palaeontological Bull. 1* (Dept. Home Affairs, Melbourne, 1932). Contains "Introductory Note" by W. G. Woolnough. 15 pp., 2 figs., 1 pl.

CALIFORNIA

"Sediments of Monterey Bay, California," by E. Wayne Galliher. *Mining in California*, Vol. 28, No. 1 (California Div. Mines, San Francisco, January 1, 1932). Issued, June, 1932. Pp. 42-79; 17 figs.; 1 pl.

CANADA

"Oil Prospects of the Great Slave Lake and Mackenzie River Areas," by G. S. Hume. *Canadian Min. Met. Bull.* (March, 1932), pp. 92-103.

FLORIDA

"Pliocene Fossils from Limestone in Southern Florida," by W. C. Mansfield. *U. S. Geol. Survey Prof. Paper 170-D* (Supt. Documents, Washington, D. C.), pp. i-ii, 43-56, pls. 14-18.

GENERAL

Jahrbuch des Deutschen Nationalen Komitees für die Internationalen Bohrkongresse (Yearbook of the German National Committee for the International Drilling Congress), Band II (1932). 360 pp., 71 illus. Laubsch and Everth, Berlin, S. W. 68.

Oil and Petroleum Year Book, 1932, by Walter E. Skinner. Twenty-third annual edition of the international standard reference book on the oil industry of the world. Statistics on American and foreign companies. New features: "Oil Field Development"; "Technical Glossary." 442 pp. Demy 8vo., red cloth. Walter E. Skinner, 15, Dowgate Hill, Cannon Street, London, E. C. 4. Price, 7s. 6d.; abroad, 8s. 6d.

"The Upper Cretaceous Ammonite Genus *Barroisiceras* in the United States," by J. B. Reeside, Jr. *U. S. Geol. Survey Prof. Paper 170-B* (Supt. Documents, Washington, D. C.), pp. i-ii, 9-29, pls. 3-10. Price, $0.20.

GEOPHYSICS

Traité pratique de prospection geophysique a l'usage des géologues et des ingénieurs des mines (Geophysical Prospecting for Geologists and Mining Engineers), by C. L. Alexanian. Librairie Polytechnique Ch. Béranger, Paris, Rue des Saints-Pères, 15. 268 pp., 133 figs., 2 pls. Price, approx., postpaid, 70 francs.

ILLINOIS

"Effects of Water-Flooding on Oil Production from the McClosky Sand, Dennison Township, Lawrence County, Illinois." *Illinois State Geol. Survey Petroleum 22* (Urbana, June, 1932). Price, $0.25.

MEXICO

El Petroleo en Mexico (Petroleum in Mexico), by Ezequiel Ordoñez. A historical study from *Revista Mexicana de Ingenieria Arquitectura* (Mexico, 1932). vii + 106 pp. 6¼ × 8¾ inches.

MONTANA

Structure Contour Map of Eastern Montana, by C. E. Dobbin and C. E. Erdmann. *U. S. Geol. Survey* (Washington, D. C., 1932). A few copies also available free at Survey offices at 523 Customhouse, Denver, Colorado, 324 Fratt Building, Billings, Montana, and at Shelby, Montana.

NETHERLANDS

"De Palaeontologie en Stratigraphie van Nederlandsch Oost-Indie" (The Paleontology and Stratigraphy of the Netherlands East Indies) and "De Palaeontologie en Geologie van Nederlandsch West-Indie" (The Paleontology and Geology of the Netherlands West Indies), by 22 authors. *Leidsche Geologische Nededeelingen* (Leiden, Netherlands), Deel 5 (1931). Volume in honor of Professor K. Martin. In Dutch, English, German, French. 748 pp., illus.

NEW YORK

"Recent Natural Gas Developments in South Central New York," by D. H. Newland and C. A. Hartnagel. *New York State Mus. Cir. 7* (1932). 20 pp.

RUSSIA

"A Contribution to the Question of the Oil and Gas of the Kalmuck Steppes," by Th. Golynetz. *Trans. Geol. Oil Inst. Ser. B, Paper 1* (Leningrad, 1931), pp. 3-17, 1 map. In Russian.

"The Oil and Gas-Bearing Chickishlar Region," by A. I. Kossyguin. *Ibid.*, pp. 19-74, 15 figs. In Russian.

"Chemical Investigations of the Natural Gases in the Melitopol Gas-Bearing Area," by A. A. Cherepennikov. *Ibid.*, pp. 75-93, 4 figs. In Russian. Summary in English.

"Brief Geological Outline of the Oil Manifestations in the Central Part of the Southern Slope of the Main Caucasian Mountain Range," by N. B. Vassoevitch. *Ibid.*, pp. 95-106, 1 map. In Russian.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 7 (JULY, 1932), PP. 709-711

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Frederick Arthur Burt, College Station, Tex.
John T. Lonsdale, E. H. Sellards, W. A. Tarr
Lawrence Yoder Faust, Tulsa, Okla.
B. B. Weatherby, John L. Ferguson, Andrew Gilmour
Cornelius Douwe Keen, Shreveport, La.
J. Y. Snyder, F. M. Van Tuyl, W. F. Chisholm
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FOR ASSOCIATE MEMBERSHIP

Elmer George Dahlgren, Oklahoma City, Okla
R. E. Rettger, William W. Clawson, Clifton M. Keeler
Thomas Harold Williams, Norman, Okla.
V. E. Monnett, C. E. Decker, G. E. Anderson

EXECUTIVE COMMITTEE MEETING, TULSA, OKLAHOMA JUNE 1, 1932

The executive committee met at Tulsa, Oklahoma, June 1, 1932. Members present were president F. H. Lahee, of Dallas, Texas, first vice-president R. J. Riggs, of Bartlesville, Oklahoma, and second vice-president W. B. Heroy, of New York City.

President Lahee announced the following appointments.

Finance committee.—Joseph E. Pogue to serve one year; E. DeGolyer to serve two years; W. E. Wrather to serve three years.

Research committee.—Ralph D. Reed and W. E. Wrather to serve one year; Alex. W. McCoy, C. E. Dobbin, A. I. Levorsen, C. V. Millikan, L. C. Snider, and L. C. Uren to serve three years.

Public relations committee.—F. H. Lahee, chairman, William H. Atkinson, Donald C. Barton, Ford Bradish, H. A. Buehler, Hal P. Bybee, Herschel H. Cooper, Carey Croneis, E. K. Soper, Luther H. White, R. B. Whitehead.

General business committee.—Frank A. Morgan, chairman.

Research fund.—Alex. W. McCoy to serve three years.

Revolving publication fund.—Frank R. Clark to serve three years.

Dallas district.—In order to create the new Tyler district in East Texas, the Dallas district was redefined to include the following counties: Grayson, Fannin, Collin, Hunt, Rockwall, Dallas, Kaufman, Van Zandt (west part), Ellis, Navarro, Henderson (west part), Limestone, Freestone.

Tyler district.—The Tyler, Texas, district was created, including the following counties: Lamar, Red River, Bowie, Delta, Hopkins, Franklin, Titus, Camp, Morris, Cass, Rains, Wood, Upshur, Marion, Van Zandt (east part to include Van and Canton), Henderson (east part to include Athens), Smith, Gregg, Harrison, Anderson, Cherokee, Rusk, Panola.

Division of Geophysics.—A charter was issued to the Division of Geophysics of the Association.

Bulletin bound volumes.—The price of the cloth-bound *Bulletin*, Volume 15 (1931), was decreased from $7.00 to $5.00 per copy, retroactive to April 1, 1932,—only one copy to members, associates, and subscribers with paid-up dues and subscriptions.

The price of cloth-bound volumes 11 (1927)-14 (1930) was increased from $4.00 to $5.00 per copy, effective July 15, 1932,—only one copy to members, associates, and subscribers with paid-up dues and subscriptions in the year of publication of the volume purchased.

Bulletin.—The number of *Bulletins* printed monthly was decreased from 3,300 to 3,000 copies, commencing with June. Also commencing with June, full blank pages at the end of articles and departments were discontinued.

ASSOCIATION COMMITTEES

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 7 (JULY, 1932), P. 712

Memorial

CHARLES ROSS SCHROYER

Charles Ross Schroyer was born at Fort Recovery, Ohio, September 27, 1887. He graduated in geology from Ohio State University in 1912 and received his master's degree in 1914. He was an instructor at the State College of Pennsylvania until 1916.

On January 27, 1916, he married Bertha Artz, of Worthington, Ohio, and until 1918 was at the University of Chicago, where he was employed as an instructor while doing post-graduate work. While at these universities, he spent his summers with the State geological surveys of Ohio, Wisconsin, and Illinois. He was a member of The American Association of Petroleum Geologists and of Sigma Xi, honorary scientific society.

He joined the geological staff of the Roxana (Shell) Petroleum Corporation in 1921 and was with this company three years working in Texas and Oklahoma. After leaving the Roxana, he spent nearly 2 years with the Ohio Fuel Oil Company at Charleston, West Virginia. It was his plan to spend 5 years in foreign work and, in 1926, he went to Colombia, where he spent 1½ years with The Colombian Oil Concessions Company. This was followed by 2 years in the Dutch East Indies with the Nederlandschi Kolonial Petroleum Maatschappij (Standard Oil Company of New Jersey), where in 1930 he became seriously ill and returned to Columbus, Ohio, where he died on June 5, 1932.

Besides his wife, he is survived by his parents and two sisters.

Ross Schroyer was an extremely hard and conscientious worker and it is thought that by overwork he hastened his death. He was quiet and reserved and always was so engrossed in his work that he could find little time for social activities. He enjoyed solving difficult problems in new areas and those who were privileged to see and discuss his work realize his exceptional capabilities as a geologist.

R. E. SHUTT

TULSA, OKLAHOMA
June 24, 1932

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 7 (JULY, 1932), PP. 713-716

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WILLARD M. PAYNE, formerly of New Orleans, Louisiana, is now employed as engineer for the McWilliams Dredging Company, Clewiston, Florida.

STANLEY C. HEROLD, geologist, Glendale, California, has an article entitled "In Defense of One's Own Work" in the June, 1932, issue of the *Oil Bulletin*.

FREDERICK G. TICKELL, professor of petroleum engineering, Stanford University, California, has a paper entitled "Modern Methods in Petroleum Geology" in the June, 1932, issue of *Mining and Metallurgy*.

ROBERT R. OSBORNE, formerly of Tyler, Texas, is now permanently located at 2003 Tower Petroleum Building, Dallas, Texas.

A. E. SMITH, geologist for the Shell Petroleum Corporation, has been transferred from Houston to Dallas, Texas.

J. BARNEY WHISENANT, geologist and valuation engineer, has moved from Big Spring to Laredo, Texas. His address is Box 143.

CARROLL E. COOK is engaged in field geology for the Kirby Petroleum Company, of Houston, Texas.

IRA M. HICKS has moved from San Angelo, Texas, to Greenfield, Illinois, where he is recuperating from a severe illness.

JAMES D. AIMER, recently employed by the Gulf Refining Company of Louisiana, may be addressed at Box 375, Nacogdoches, Texas.

MISS WINNIE MCGLAMERY is paleontologist for the Alabama Geological Survey, University, Alabama.

JOHN R. SUMAN, director of production for Humble Oil and Refining Company, heads a party composed of W. W. SCOTT, chief engineer of Humble Oil and Refining Company; E. L. ESTABROOK, chief engineer of Pan American Petroleum and Transport Company; and HARRY HILL, Standard Oil Company of New Jersey, who have been inspecting Standard Oil Company of New Jersey property in Venezuela.

S. L. GILLAN, consulting geologist of Los Angeles, has returned to California after a trip around the world. He was accompanied by Mrs. Gillan.

GRADY C. KIRBY, who has been divisional geologist for the Sinclair-Prairie Oil Company in the Gulf Coast region with headquarters in Houston, has been transferred to San Antonio, where he will be in charge of geological work for the company in South Texas.

V. E. COTTINGHAM, deputy supervisor for the oil and gas division of the Texas Railroad Commission, has been transferred from East Texas to San Angelo.

ROY H. HALL is employed in consulting geology in Wichita, Kansas.

ARTHUR F. TRUEX, of Tulsa, is in charge of the land and geological departments of the Twin State Oil Company.

EUGENE HOLMAN, who was appointed assistant to E. J. Sadler, director in charge of foreign producing operations of the Standard Oil Company of New Jersey, in 1929, has been made vice-president of the Pan American Foreign Corporation, in charge of production, president of the Lago Petroleum Corporation, vice-president of the Lago Oil and Transport Company, Ltd., and a director in six of the Pan American holding and operating companies.

FRED H. KAY, who was appointed assistant to the vice-president in charge of production of the Pan American Petroleum and Transport Company in 1926, has been made vice-president and director of the Mexican Petroleum Company, Ltd., of Delaware, the Huasteca Petroleum Company, and the Mexican Petroleum Company of California, and director of the Lago Petroleum Corporation.

EDWARD L. ESTABROOK, who went with the Pan American Petroleum and Transport Company in 1925, is now a director in the Lago Petroleum Corporation, the Mexican Petroleum Company, Ltd., of Delaware, the Huasteca Petroleum Company, and the Mexican Petroleum Company of California.

C. R. SCHROYER, of the Shell Petroleum Corporation, died in California, June 4, 1932, after an illness of several months. Schroyer worked in Batavia, Dutch East Indies. His home was at Worthington, Ohio.

ALEX. W. MCCOY, of Ponca City, is a director in the newly chartered Marland Oil Company of Oklahoma.

D. R. KNOWLTON, H. C. CHARLES, and D. A. MCGEE are co-authors of a paper, "Data on 'Wilcox' Sand at Oklahoma City," in the June 9 issue of *The Oil and Gas Journal*.

J. W. BEEDE, professor of geology in the University of Indiana, and BERTE R. HAIGH, adjunct professor of geology in the Texas School of Mines at El Paso, are in San Angelo doing special work on the University lands during the summer.

The San Angelo Conglomerates, organization of petroleum geologists, San Angelo, Texas, have elected the following officers for the ensuing year: Big boulder (president), NATE ISENBERGER; gravel (first vice-president), ROBERT L. CANNON; gravel (second vice-president), RUSSELL CONKLING; eroding agent (treasurer), J. F. HOSTERMAN; log plotter (secretary), PAUL SCHLOSS; bottle grabber and sampler, H. A. HEMPHILL; chief scout (bulletin editor), CAREY P. BUTCHER; transportation agent, in charge of field trips, HENRY MORGAN; notoriety agent, FRANK E. LEWIS; sergeant at arms, D. S. LOUNS-

BERRY. ROBERT T. HILL, well-known geologist of Dallas, lectured to the organization in June on "A Century of American Geology."

K. C. HEALD, geologist for the Gulf Oil Company, Pittsburgh, has a paper in the June 16 issue of *The Oil and Gas Journal*, entitled "Use of Geophysics in Prospecting for Oil Is Not Mysterious."

K. B. NOWELS, Forest Oil Corporation, Bradford, Pennsylvania, has an article entitled "Recent Developments in Production, Field Practice and Operation in Bradford," in the June 16 issue of *The Oil and Gas Journal.*

C. A. WARNER, geologist, Tulsa, Oklahoma, has a paper entitled "General Geology of Edwards Plateau, Balcones Fault, and Gulf Coastal Plains Regions," in the June 16 issue of *The Oil and Gas Journal.*

FREDERIC H. LAHEE presented a paper on "Geology and the New Conception in Field Development" at the American Petroleum Institute meeting in Tulsa, Oklahoma, June 2. It was published in *The Oil Weekly* of June 6.

History of The Geological Society of America, 1880-1930, a book of 232 pages and 18 plates, by H. L. Fairchild, has just been published by Judd and Detweiler. The price is $2.50. The address of the society is 118th Street and Amsterdam Avenue, New York City.

The ninth annual field trip of the Shreveport Geological Society on June 10, 11, and 12, 1932, was routed over the Tertiary formations of Mississippi and Alabama. The trip was taken by 25 geologists. A printed pamphlet of 14 pages, including a list of the principal publications about the Tertiary geology of Alabama and Mississippi, the itinerary of the trip, 2 maps, and a correlation table, was issued to the members of the party. The trip committee was composed of A. F. CRIDER, chairman, R. T. HAZZARD, B. W. BLANPIED, and W. C. SPOONER.

W. P. JENNY, geologist and geophysicist with the Magnolia Petroleum Company at Dallas, Texas, expects to be in Ohio for the summer months. His temporary address is Strasburg, Ohio.

ELIOT BLACKWELDER, professor of geology at Stanford University, California, has a paper in the May-June, 1932, issue of *The Journal of Geology*, entitled, "An Ancient Glacial Formation in Utah."

WILLIAM W. PORTER, geologist, Los Angeles, has a paper entitled "The Coahuila Piedmont, A Physiographic Province in Northeastern Mexico," in the May-June, 1932, issue of *The Journal of Geology.*

H. V. TYGRETT, geologist for the Atlantic Oil Producing Company, who has been in Matanzas, Cuba, is now in Dallas, Texas.

J. R. PEMBERTON has moved from Los Angeles, to 525 North Palm Drive, Beverly Hills, California.

H. HEMMINGS, formerly of The Hague, Holland, is now in Maracaibo, Venezuela, for the Caribbean Petroleum Company.

NOEL H. STEARN, chief geologist for the Silurian Oil Company, and for W. C. McBride Company, has been made vice-president of the Southwestern Quicksilver Company, which owns the first mine to be put into operation in the new Arkansas quicksilver district.

CLAUDE F. DALLY and VICTOR E. EKHOLM have opened a consulting office at 610 Fort Worth National Bank Building, Fort Worth, Texas, under the name of Dally and Ekholm.

ELFRED BECK, formerly chief geologist for the Producers and Refiners Corporation, Tulsa, has opened a consulting office at 528 Exchange National Bank Building, Tulsa, Oklahoma.

WALTER S. OLSON has returned from Bandoeng, Java, Dutch East Indies, and is now at Taylors Falls, Minnesota.

CHARLES E. DECKER, professor of paleontology at the University of Oklahoma, is at Albany, New York, this summer, working in the New York State Museum on the graptolites and associated fossils of the Viola limestone.

H. K. SHEARER is geologist for the Pelican Natural Gas Company, at Shreveport, Louisiana.

URBAN B. HUGHES, of Iowa City, Iowa, is temporarily located at Laurel, Mississippi, while engaged in consulting work.

R. W. BRAUCHLI, chief geologist, Anderson-Pritchard Oil Corporation' Oklahoma City, Oklahoma, has an article entitled "Estimate of Ultimate Production from the North Wilcox Area of Oklahoma City Field," in the *Oil and Gas Journal* of June 23, 1932.

J. WHITNEY LEWIS is in Los Angeles, California, for the summer. His address is 1432 Victoria Avenue.